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**Representational Redescription  
and the Development of  
Cognitive Flexibility**

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**Submitted for  
Doctor of Philosophy  
Cognitive Science  
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## **Abstract**

### **Representational Redescription and the Development of Cognitive Flexibility**

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Karmiloff-Smith (e.g. 1986, 1992) has suggested that 'cognitive flexibility' is the result of a series of three representational redescrptions. These redescrptions are carried out by endogenous metaprocesses operating directly on the representations. Representational redescription accounts only for development beyond 'behavioural success', the stimulus to the redescription being stability at a previous level.

Many features of the Representational Redescription theory are criticised, but the underlying idea that cognitive flexibility is associated with representational level is maintained. This point is supported by a review and study of planning development arguing that representational development, rather than process development explains increasing flexibility.

Data from children's drawings and block balancing, along with a theoretical analysis of the model indicate that the details of the Representational Redescription theory are not consistent or plausible. In particular the concepts of initial procedural representation, endogenous metaprocesses, behavioural success, stability as the spur to development, and implicit information within representations, are

rejected.

Removing the constraints of behavioural success suggests a new recursive model, which is proposed as a general developmental mechanism. 'Recursive Re-Representation' views representational redescription as a *creative* process, and builds on Boden's (1992) computational approach to creativity. Cognitive flexibility is determined by a limited cognitive capacity, the level of 'chunking' in a domain and the possession of an overview of the relevant conceptual space. Chunking is achieved through a re-representation of behaviour and the environment, rather than a direct operation on representations. The BAIRN system (Wallace, Klahr & Bluff, 1987) is suggested as providing the basis for an implementation of Recursive Re-Representation.

It is argued that the Recursive Re-Representation account which views Representational Redescription as a recursive, creative process provides a more parsimonious approach to representational change throughout development.



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# Chapter 1

## Thesis overview

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### 1. Introduction

This research began with an interest in understanding 'reflective' processes in adults, and a desire to clarify the concept of 'metacognition'. It became apparent that the key to understanding adult functioning was to understand the developmental history of such abilities. This thesis combines both developmental and computational approaches, taking a cognitive science perspective; a strategy advocated by both Karmiloff-Smith (1992) and Rutkowska (1987). The aim of the research was to explore the concept of and to provide some explanation for the development of cognitive flexibility in adults as well children, rather than a description of child development *per se*.

The title of this thesis refers to the development of 'cognitive flexibility', a term coined by Karmiloff-Smith (1992). Karmiloff-Smith is concerned with the ability of humans to go beyond successful task execution, to be aware of and to reflect on their performance. This is what differentiates humans from other animals allowing them to be

"... creative, cognitively flexible and capable of conscious reflection,  
novel invention, and occasional inordinate stupidity."

Karmiloff-Smith 1992 (p.1)

'Cognitive flexibility' is used in this thesis as the most inclusive of these

ill-defined terms. Use of the term is meant to include various related ideas: reflective thinking, awareness of knowledge, conscious reflection, and metacognition.

The development of 'cognitive flexibility' has not been central to most theories of development. There was a lot of interest in 'metacognition' in the 1980's, but this was not linked to any broader developmental theories. Karmiloff-Smith is one of the few developmental psychologists to investigate cognitive flexibility and to adopt a cognitive science approach. She has proposed a theory of 'Representational Redescription' (RR) to explain the emergence of cognitive flexibility after behavioural success (Karmiloff-Smith, e.g. 1984, 1986, 1992, 1994). This thesis will argue for a representational redescription<sup>1</sup> account, although Karmiloff-Smith's (1986) model will be reformulated as a recursive, creative process and proposed as a general developmental mechanism. It will be argued that the concept of representational redescription is a useful one, but that Karmiloff-Smith's (1986) particular model is neither theoretically consistent, nor empirically supported. An alternative model called 'Recursive Re-Representation' (3R's) will be proposed, as a more parsimonious account. In the following sections, the thesis will be outlined chapter by chapter.

## **2. Chapter 2**

Cognitive flexibility has been studied under many different headings, principally 'metacognition', but also 'awareness' and 'reflection'. In

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<sup>1</sup> Representational Redescription with initial capital letters will be used to refer to Karmiloff-Smith's theory, representational redescription in lowercase will refer to the more general concept.

chapter 2, the concept of metacognition is discussed, in particular the widely quoted account of Flavell (1979). An initial analysis of the concept finds that there is nothing 'meta', in terms of 'higher order', about metacognition. 'Metacognitive knowledge' and 'metacognitive experiences' differ from other knowledge and experiences only in their domain of concern: the mind. This is reflected in the concern of current researchers with 'theory of mind', rather than 'metacognition'. The processing aspect of Flavell's account 'cognitive monitoring' remains less clear, although it seems to involve awareness and evaluation processes. Although ill-defined it does not seem to be distinct from other 'higher cognitive processes', and no account of its development is offered by Flavell (1979, 1987).

Vygotsky has proposed that 'higher cognitive processes' develop through the internalisation of social regulation processes. Wertsch, pursuing Vygotsky's theory, has described a shift of regulation process from mothers to children in a puzzle completion task. Wertsch's experiments illustrate the argument, but do not explain the mechanisms; 'internalisation' remains an ill-defined process.

Karmiloff-Smith (e.g. 1986) has provided the most formal account of the processes involved in the development of cognitive flexibility. She has, over a number of years, and in a number of domains, developed a detailed model of Representational Redescription. The RR model begins with successful performance in a domain, and suggests that cognitive flexibility results from a series of redescriptions of the domain knowledge into increasingly accessible formats. Four levels of representations are described, culminating in a linguistic representation, the redescriptions being carried out by endogenous metaprocesses. The metaprocesses operate directly on the

representations, extracting implicit regularities and representing them explicitly in a new format. The RR model is outlined in more detail in chapter 2.

Karmiloff-Smith (1986) provides the only Cognitive Science approach to cognitive flexibility. The RR model held the promise of a formal account of cognitive flexibility, and thus provides the focus for this thesis. The RR model is specified in considerable detail and makes a number of falsifiable claims, some of which are tested in this thesis.

The RR model is described in detail in Karmiloff-Smith's 1986 paper. The portion of the model which has been developed in the most detail is the series of representational formats. One specific detail from this account - the initial representational format - was then empirically supported in a later paper (Karmiloff-Smith 1990) with evidence from children's drawing. The 'metaprocesses' which perform the redescriptions are less well formulated. The evaluation of the RR model begins in chapter 3 by examining Karmiloff-Smith's (1986, 1990) claim that the initial representations, which produce successful performance, are 'compiled procedures'. These 'compiled procedures' provide the basis for further redescriptions to higher, more accessible levels. In a study of children's drawings, Karmiloff-Smith (1990) demonstrated that young children could not produce certain types of modifications to their standard drawings to produce a 'strange' drawing. She claimed particularly that modifications which required 'operating on a procedure' were not possible for younger children, they were only able to add or delete elements at the end of executing a complete procedure.



### 3. Chapter 3

Chapter 3 describes a partial replication of this study, with greater controls and concludes that the initial representations are neither compiled nor procedures. The representations are more flexible than that. However, the difference in types of modifications between age groups was replicated. It is concluded that these differences could either reflect differences in planning ability or differences in inventiveness between age groups. Both explanations, the development of planning and creativity, are followed up later in the thesis.

RR theory is only concerned with development beyond 'behavioural success', however, this point of 'success' was shown to be hard to define in the drawing domain, and will be shown to be a fundamental problem for the RR model. Chapter 3 licences the rejection of the initial representational format suggested by the RR model, but this is only a small part of the RR theory. It is arguable that the problems identified in chapter 3 might relate specifically to the drawing domain. The complete RR account is supported with data from a number of domains (Karmiloff-Smith 1992), so a broader view needed to be taken and different tasks investigated.

One of Karmiloff-Smith's most quoted examples is her 'block balancing' task (originally Inhelder and Karmiloff-Smith 1974). In this task, subjects are required to balance a selection of evenly and unevenly weighted blocks across a narrow bar. Some of the the unevenly-weighted blocks have obvious weights and others contain hidden weights and are visually identical to the evenly weighted blocks.

The block balancing domain as described by Karmiloff-Smith (1984) seemed to provide some of the clearest and strongest support for the RR

model. The domain allows a clear distinction between success and failure: a block either balances or it doesn't. It is also reported as producing a U-shaped behaviour, which provides behavioural evidence of underlying representational changes which follow initial successful performance. Karmiloff-Smith (1984) suggests that initial successful performance is produced by an un insightful proprioceptive procedure (phase 1) which leads to success with all the blocks. Subsequent failure (phase 2) is produced by an over-general dominating 'theory' that everything balances in the middle. The final success (phase 3) is accompanied by awareness and produced by a flexible procedure.

#### **4. Chapter 4**

A replication of the block balancing task was performed and is reported in chapter 4. It included the collection of some quantitative data (balance time), which had not been reported by Karmiloff-Smith. The prediction was that the different representational phases would produce different patterns of balancing times. Phase 1 subjects should produce equal times for all blocks, as there should be no preference for a centred balancing position. The phase 2 subjects should fail on all but the evenly-weighted blocks, due to their centre-fixation. Final successful performance should reflect longer times for the off-centre balances, as the centred position is tried first. However, the replication did not produce unequivocal support for the 1986 model. There was some evidence of the rigid 'phase 2' performance, but there were also intermediate patterns of block balancing which were not accounted for by the model. There was no difference in the pattern of timings between age groups, which indicated a 'central tendency' in all subjects. Case studies, presented in chapter 4, more closely resembled the results

of the original observational study (Inhelder and Karmiloff-Smith 1974) than later descriptions of the task (e.g. Karmiloff-Smith 1984). The former study reported a wider range of balancing behaviours. The case studies highlighted the importance of the *encoding* of the problems which, it is argued, reflects developing knowledge of the problem. It was the ability to analyse the blocks on the relevant dimensions which characterised flexible performance. Knowledge development seems to account for performance, an explanation which accords in general terms with Karmiloff-Smith, although the specific RR model is not supported.

## 5. Chapter 5

In chapter 5 the RR model is analysed further in purely theoretical terms. The evaluation described here provides the basis for a new account to be developed in chapter 9. The RR model (Karmiloff-Smith 1986) was presented as a computational account of development, so an implementational approach is adopted. The details of the initial representations, as compiled procedures, were rejected in chapter 2. But beyond the specific representational formalism, there are also fundamental problems with the idea that the initial representations are inaccessible. Karmiloff-Smith (1986) suggests that (to use her terms) information which is 'implicit' in a 'plethora' of initial procedures, is extracted by the redescription metaprocesses, and then explicitly represented. The concepts of 'implicit' information and a 'plethora' of procedures create the problem of an information explosion. There must be some limit to the information which is encoded in the initial procedures. Some access to content is also required in order that 'domains' can be delimited, and 'stable success' recognised, both of which are prerequisites of redescription in the RR model. This problem

is confounded by the endogenous nature of the redescription processes, operating directly over the representations. It is suggested that extracting regularities from *behaviour* rather than from *representations* relieves part of the problem, and this approach is pursued in the 3R's model (presented in chapter 9).

The operation of the 'metaprocesses' is underspecified in the model, and the stimulus to redescription, 'stable success' is also hard to define, computationally. The case studies in chapter 4 suggested the possibility that 'surprise' might be an alternative candidate for the latter. The 'metaprocesses' are replaced by a 'perceptual analysis' mechanism which operates over behaviour and the output of representations, rather than the representations themselves.

The issue of 'behavioural success', which was raised as a problem in chapters 3 and 4, is rejected in chapter 5. It is argued that 'success' puts an unjustified barrier between representational redescription and more general theories of development. However, dropping the constraint of behavioural success has serious ramifications in various parts of the model. Significant reformulations are required; a fundamental change is that the limited series of 3 phases and 4 representational formats needs to be dropped, as a recursive approach is adopted. The 3R's model (presented in chapter 9) employs a recursive redescription mechanism, operating over a single representational format. Eliminating 'behavioural success' broadens the applicability of representational redescription, allowing it to be considered as a general developmental mechanism.

## 6. Chapter 6

Karmiloff-Smith's RR model is left in chapter 5, and attention is

focussed on an alternative approach to the development of cognitive flexibility. Vygotsky's idea that it is the higher cognitive processes which develop is introduced in chapter 2, and chapters 6 and 7 focus on one particular example: planning. The development of planning is suggested as a potential explanation of the empirical results presented in chapters 3 and 4. In chapter 6, a number of approaches to planning development are reviewed. No detailed account of developmental mechanisms are found, although the general consensus seems to favour process development explanations.

## 7. Chapter 7

Chapter 7 introduces Magkaev (1977) and Isaev's (1985) model of planning development. This provided the most detailed account of a developmental progression in planning. The account was developed in the Soviet tradition, and is assumed to incorporate Vygotsky's 'internalisation' mechanism. Isaev's model proposes three 'post-success' behavioural stages, and it seemed to provide an interesting basis for a comparison with Karmiloff-Smith's RR theory.

Isaev's model suggests four phases of planning development: *manipulative*; *step-by-step*; *short-range*; and *theoretical*. The *manipulative* subjects are not really engaged in 'planning'. The task goal cannot be held in memory as well as the task rules, and although the subject moves within the rules, she does not succeed in reaching the goal. *Step-by-step* planning indicates a lookahead of a single step, whilst *short-range* planning has a larger lookahead. Both approaches are successful, but they are not able to produce optimal (minimum move) solutions. The most advanced level of planning, the *theoretical* approach, involves the consideration of alternative plans, and the

selection of the optimal one.

Isaev (1985) supports his model with evidence from a train-shunting task. The task involves re-organising a numerically-labelled sequence of train carriages by moving and leaving carriages on certain tracks. The problem involves analysing the problem space, to eliminate the redundant tracks from consideration. A partial replication of Isaev's train task with both children and adults, is presented in chapter 7. Here, as in the block balancing task, the results are not as clear cut as predicted by the initial study and quantitative analyses were not applicable. Case studies, provided evidence of *manipulative, step-by-step* and *short-range* planning, although there was no evidence of *theoretical* planning. The results from the adult case studies (interpreted from a cognitive science perspective), indicate that planning level is not a general developmental stage of the individual, but is the result of the interaction between an individual's encoding<sup>2</sup> and the cognitive load of the task. The results are taken to implicate the development of domain knowledge rather than the development of planning processes *per se*. Representational redescription as a general account of development, will claim that representational change, rather than the development of new higher cognitive process will explain development. The results from chapter 7 are consistent with this view.

## 8. Chapter 8

Chapter 8 marshals further supporting evidence for the 'knowledge development' approach, to justify the extended re-formulation of

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<sup>2</sup> The word encoding will be used to refer to the representational process: the perceptual encoding process involved in interpreting a stimulus. This will be distinct from the simple term 'representation' which will be used to refer to knowledge structures in memory.

representational redescription which is presented in chapter 9. It is argued that apparent developmental differences in processes can be explained by differences in knowledge. The apparent development of higher cognitive processes, is a feature of the interaction between the processes and the child's knowledge base (e.g. Chi and Ceci 1987). The complementary evidence of 'early competence' indicates that children do possess higher cognitive processes at an early age, but they can only use them where they understand the knowledge content of the questions. Identifying the analogy between two instances of 'grasping', for example, will not appear as complex as recognising analogous problems in physics, but the basic comparative processes are the same - the differences relate to content.

## **9. Chapter 9**

In chapter 9 a new account of representational redescription, called 'Recursive Re-Representation' (3R's) is developed. It is a recursive model, incorporating the theoretical and empirical concerns raised earlier in the thesis. The differences between the 3R's model and the RR model are substantial enough that the 3R's model cannot be considered a variant under RR theory (Karmiloff-Smith 1992). However, whilst many features of the RR model are criticised in this thesis, the underlying principles are maintained and provide the basis of the 3R's account.

Cognitive flexibility is attributed to the contents of working memory, which has a limited capacity in terms of 'chunks'. Awareness will access whatever is contained in working memory. In absolute terms, the amount of information contained in working memory will increase with knowledge development and the associated development of

encoding capabilities. Flexibility in any limited domain, will be dependent on what can fit within the limited central capacity, the quantity of knowledge being fixed in terms of 'chunks'.

Recursive Re-Representation produces new 'chunks', with 'chunking' envisaged as starting with the most basic sensations in infancy. As a recursive process its operations continue into expertise, which is a more common domain for the chunking concept. The hierarchical knowledge structure is related to awareness in a way comparable to that suggested by Activity Theory. However, the 3R's account draws on the insights of Activity Theory, without adopting the theoretical perspective.

In place of Karmiloff-Smith's four representational formats, and redescription metaprocesses, the 3R's model proposes a recursive process of 'Re-Representation', where the encoding processes which create the most basic representations, can also create the higher level representations. Mandler's (1988, 1992) 'perceptual analysis' mechanism provides a general description of the type of processes involved. Chunking is achieved through a re-representation of behaviour and the environment, rather than a direct operation on the representations. It is suggested that Re-Representations are triggered by affective responses, e.g. surprise. It is argued that this account is more parsimonious than Karmiloff-Smith's, providing a consistent approach to representational change throughout development.

The basic principle that cognitive flexibility is associated with representational level is maintained. This point is supported by the review and study of planning development (chapters 6 and 7) arguing that representational development, rather than process development is explanatory.



Having dropped the constraint of behavioural success, the 3R's account proposes a recursive representational development process which is operative from infancy to expertise. RR theory has been used to explain creativity (Karmiloff-Smith 1993 and Boden 1992, 1993). However, it is argued, representational redescription is itself a creative process. The 3R's account draws on Boden's (1992) computational approach to creativity. She does not elaborate her model in the cognitive development domain, although her insight that 'creativity allows thoughts that could not have been thought before', is particularly helpful in understanding development. Her approach explains creativity with reference to processes which it is shown are present in infants.

Boden characterises creativity as the mapping and transformation of conceptual spaces. Knowledge elaboration, accounts for the mapping of a domain, and representational redescription accounts for the transformation (re-conceptualisations) of the conceptual spaces, which create new perspectives on knowledge.

The BAIRN system (Wallace, Klahr, and Bluff, 1987), a rare developmental program, is described and compared with the 3R's model. It contains many of the relevant components identified in Recursive Re-Representation: it is recursive, creative, and progresses on the basis of evaluating performance. It is presented as a promising basis for developing the 3R's model.

## **10. Chapter 10**

This thesis argues that representational redescription, viewed as a creative, recursive process is a general developmental mechanism. The

thesis ends with suggestions, presented in chapter 10, for further developing the approach and the 3R's model.

## Chapter 2

### Cognitive Flexibility and Cognitive Development

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#### Chapter Abstract

In this chapter a number of accounts of cognitive flexibility are reviewed, in an attempt to clarify the concept, and to discover its developmental origins. There is little clarity surrounding discussion of *what* develops; the concept of 'metacognition' in particular is examined and rejected. The focus of the latter half of the chapter is on *how* cognitive flexibility might develop. The Soviet approach of internalisation is reviewed, and this is discussed further in chapter 7. It is argued that Karmiloff-Smith (e.g. 1986, 1992) has provided the most promising account from a cognitive science perspective. This account is presented in detail, and forms the focus of this thesis.

#### 1. Introduction

Cognitive flexibility, Karmiloff-Smith (1992) argues, is what differentiates human cognition from that of animals. What is special about human cognition is our ability to go beyond *using* knowledge to *reflecting* on knowledge. The general term 'cognitive flexibility' will be used as a general term to refer to reflective thinking, awareness, and metacognition. Cognitive flexibility is ill-defined, the vagueness of the term reflecting the confusion in the definition of the subordinated

concepts, some of which will be discussed in this chapter. In the thesis Karmiloff-Smith's distinction between using and reflecting on knowledge will be clarified.

There are two general approaches possible in discussing the development of 'cognitive flexibility'. Firstly the definition of *what* it is that develops, and secondly defining *how* that development takes place. The *what* will not be well tied down in this chapter, but various descriptive approaches will be reviewed. The vague nature of the concept of 'cognitive flexibility' means that a lot of descriptive rather than explanatory developmental work has been done. The chapter begins by considering the popular concept of 'metacognition' which includes both knowledge and process, as a possible explanation of *what* develops. Metacognition will be shown to be an unhelpful concept and consequently, it will be left without reviewing any accounts of *how* it might develop.

There are three basic types of explanations for *how* cognitive flexibility develops: the development of knowledge, the development of structure or the development of processes. Domain general structural accounts (e.g. Piaget's 1983) have largely fallen out of favour, and will not be considered in detail, but both *process* and *knowledge* development approaches will be considered in this thesis. The knowledge development approach appeals to changes in the structure of knowledge, these changes explain differential access to pre-existing higher cognitive processes. In the process development approach, it is awareness and the higher cognitive processes themselves which develop.

The process development view, typified by Vygotsky (1962), and Wertsch (1985) suggests that the development of domain general

cognitive processes explains increased cognitive flexibility. Higher cognitive processes, e.g. planning, reasoning, which require cognitive flexibility, are believed to be undeveloped in young children. The developmental mechanism which will bring them into being, is the internalisation of social-regulatory processes.

It is clear that older children *ceteris paribus* know more than younger children. It is also obvious that flexibility in a domain presupposes the possession of knowledge in that domain. No-one argues against the idea that knowledge is acquired during development. This thesis will be concerned not simply with the mere accumulation of knowledge, but with the development of the *structure* of knowledge, as well as the content. This approach is typified by Karmiloff-Smith (e.g. 1986) whose 'Representational Redescription' model explains cognitive flexibility as dependent on representational format. Karmiloff-Smith's model is outlined at the end of this chapter, and forms the focus of this thesis.

## **2. Cognitive Flexibility**

Cognitive flexibility refers to what it means to think about something, or to understand something, to take some area of knowledge, as the object of cognition. This clearly includes and requires 'consciousness', but consciousness will be assumed rather than explained in this thesis. There are a wide variety of terms that will be subsumed under the umbrella of cognitive flexibility. These terms are mainly used descriptively, with no account of developmental mechanisms. A few terms are briefly reviewed in this section, with the most widely used concept 'metacognition' being discussed in the next section.

Johnson-Laird (1988) has produced a 'taxonomy of thinking' in which he identifies 'self-reflection' as the higher order element of thinking.

"We have the capacity to reflect upon what we are doing - our own process of thought becomes itself an object of thought at a higher level ... self-reflection does not stop here. It too, can be the object of itself: you can think about your own metacognitive thoughts."

Johnson-Laird 1988 (p. 450-451)

Johnson-Laird admits that his analysis is at Marr's (1982) computational level (what the mind is doing) rather than at the algorithmic level (how it is doing it). However, even the computational analysis is not very detailed. He places 'self-reflection' outside of the taxonomy, stating that 'self-reflection' is a higher level of operation applicable to all other thought processes. It is a 'meta' level process, and no account of its interaction with the lower levels nor of its development are offered. However, Johnson-Laird has created a problem with a potentially infinite number of levels of reflection. The concept of 'meta' levels of thought are discussed further in the next section on metacognition

Awareness and reflection are often implicated in the regulation of cognition. Brown and De Loache (1983), stress predicting, checking results and monitoring progress and Yussen (1985) includes planning in his list of 'metacognitive' skills, which are used to monitor and control our performance. These 'skills' are general higher cognitive processes which are required for flexible performance in a domain. What is less clear is their developmental origins: whether they are features of cognition which apply when knowledge is in the correct format (see Karmiloff-Smith section 6), or whether they are general skills. Brown &

De Loache (1983) argue that metacognitive skills are both broadly applicable, and also that they are domain specific.

"Novices often fail to perform efficiently, not only because they may lack certain skills but because they are deficient in terms of self-conscious participation and intelligent self-regulation."

Brown and De Loache 1983 (p. 139)

Self-conscious participation and intelligent self-regulation are not defined further. An account of development is required to clarify if, or to what extent, these abilities develop independently of any particular knowledge domain or are linked to a specific knowledge domain. The studies of teaching metacognitive 'skills', has generally shown a failure to transfer between domains, which might be taken to argue for the latter position. The development of planning is considered in detail in chapters 6 and 7 of this thesis. The issue of whether there is anything essentially 'meta' about 'metacognition' is discussed in section 3.

## **2.1 Self regulation and Cognitive monitoring**

Brown and De Loache argue that metacognitive skills are a function of expertise in a domain. Children are novices on many tasks, and it has been argued that they also lack general metacognitive skills (Flavell and Wellman, 1977; Brown 1978). An explanation for this is that the experimental tasks tested are new and difficult for children. "This does not mean that children are incapable of self-regulation, only that they tend not to bring such procedures to bear immediately on new problems."

Brown and De Loache (1983) suggest the following developmental pattern

"First the absolute novices show little or no intelligent self-regulation. then as the problem solver becomes familiar with the necessary rules and sub-processes, he enters into an increasingly active period of deliberate self-regulation. Finally, the performance of the expert would run smoothly as the necessary sub-processes and their co-ordination have all been overlearned to the point where they are relatively automatic."

This is not a function of age - but one of expertise. This progression is also shown by Simon and Simon (1978) and has been illustrated in various fields e.g. Chi (1977) in chess; Markman (1977) with young card players.

An essential part of the regulation of cognition involves the *awareness* of cognitive processes. But awareness itself is not a process, but a feature of cognition. We are always 'aware' of something, but it is not clear how awareness is implicated in development.

Robinson (1983) has looked at the role of awareness in development. She has framed the following questions:

"Is awareness of inadequacy in one's current way of thinking responsible for advances? On the other hand, is awareness of one's thinking activity a relatively late development which allows that activity to become more planful and regulated? Does one become aware of how one is thinking when problems arise, or when one is coping easily with spare cognitive capacity to watch what one is doing?"

Robinson 1983 (p.107)

These provide a useful framework, but Robinson does not suggest any answers to these questions. Instead she concludes that little is known about how awareness interacts with knowledge, or whether it facilitates or results from cognitive development. Robinson equates 'awareness'



with 'metacognition' which will be discussed further in the next section.

Markman (1977) presented 5 to 8 year-old children with incomplete instructions for solving a performing a magic trick, or playing a game. The youngest children, when probed, are not aware of the inadequacy of the communication until they attempt to play the game or perform the trick, and find that they cannot proceed. Robinson (1983) makes a further distinction between a child's knowing that, for example, there is a problem in understanding an ambiguous message, and with locating the problem in the message. She identifies this as the difference between knowing *that* you don't know and knowing *why* you don't know. Brown (1978) describes a similar progression from knowing how to use strategies, to knowing that you are using strategies. She describes the case of a 7-year-old boy who sorted cards into categories without being aware that he was sorting into categories, he claimed he was just looking at them. However, no explanation of this progression in awareness is offered by either author. The experiment demonstrates an increase in the contents of awareness, but this could be equally well explained as increased domain knowledge, or as an expansion of awareness, analysing processes, or the increase in processing capacity.

There is general agreement that children's awareness of tasks increases with age, and that 'awareness' is a constituent of the monitoring process, but, there is no account of what it means, in representational or processing terms to be 'aware' of one's knowledge.

Brown (1987) has argued that there is much confusion in the terms that have been used to describe 'understanding', and advocates that attention is directed towards the mechanisms of change. This is the approach adopted in this thesis. The use of the term 'cognitive

flexibility' will remain ill-defined, the idea is captured by Karmiloff-Smith's distinction between using knowledge and reflecting on knowledge.

### 3. Metacognition

A number of psychologists have the abiding intuition that metacognition is an extremely important topic, eminently worthy of further theoretical and experimental investigation. However, none of us has yet come up with deeply insightful, detailed proposals about what metacognition is, how it operates, and how it develops.

Flavell 1987 (p. 28)

Cognitive flexibility has been widely researched under the heading of 'metacognition'. Flavell's initial use of the prefix 'meta-' (Flavell, Freidrichs, and Hoyt 1970) stimulated a lot of research on metacognition in the seventies and eighties. His conclusion, quoted above, is rather depressing following, as it does, 17 years of research. This section reviews the concept, as defined by Flavell (1979) and questions whether there is any need to posit a 'meta-level' of functioning to explain reflective thinking. It concludes by arguing that 'metacognition' is not a useful concept in explaining cognitive flexibility.

#### 3.1 Defining the 'meta' in metacognition.

Flavell (1979; 1981; 1987) defines metacognition very broadly as knowledge and cognition *about* anything cognitive or psychological. The Concise Oxford dictionary does not list, amongst the various meanings of the prefix 'meta-', a sense meaning 'about'. A more usual interpretation of the prefix 'meta', in 'metacognition', would be "of a higher or second-order kind" (Concise Oxford dictionary). This would

clearly distinguish 'metacognition' from 'cognition', in a way comparable to the use of 'meta' in the concept of a 'metalanguage' in formal semantics. Here logic is used as a metalanguage, in which to describe a natural language, although it is not itself a part of that language. The term 'meta'-cognition suggests (second-order) processes which operate on cognitive knowledge or processes, rather than directly on data from the outside world.

Flavell's broad definition of 'metacognition' as 'cognition *about* cognition' has been widely used within the field (e.g. Baker and Brown 1984; Weinert and Kluwe 1987; Yussen 1985), and although the emphases within these accounts do vary, they all lack the 'second-order' idea. To avoid confusion a new term 'supercognition'<sup>1</sup> will be used to refer to the conception of second-order cognitive processes. This is not to imply that a distinction between cognitive and supercognitive processes is useful or important. It merely serves to distinguish this specific conception of 'metacognition' from the various other 'meta-' terms that will be discussed. Hereafter, we will only use terms with the prefix 'meta-' when describing the work of researchers who have themselves employed that terminology. Supercognition refers to a higher level of cognitive processes, and not to hierarchical representations or knowledge content.

### **3.2 Flavell's taxonomy**

Flavell (1979) proposed a taxonomy of metacognition as a first step in studying the domain, but has not made any claims for its exhaustiveness and limited claims for its usefulness Flavell (1987). As

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<sup>1</sup> The prefix 'super-' comes from the Latin, on top (of), above, beyond. As 'cognition' is also of Latin derivation, 'super-cognition' is, in fact, a more etymologically consistent term than 'metacognition' which mixes Greek with Latin.

it has been widely used as a basis (e.g. Brown, Robinson 1983; Yussen 1985) and was the first and most general attempt to map the complete domain it provides a focus for discussing metacognitive research.

Flavell (1979, 1981, 1987) divides his broad conception of metacognition as 'cognition about cognition' into two specific categories which are: metacognitive knowledge and metacognitive experience. He describes metacognitive knowledge as knowledge about cognitive processes. Metacognitive experiences are also broadly defined as

"any conscious cognitive or affective experiences that accompany and pertain to any intellectual enterprise"

Flavell 1979 (p. 906)

These are the feelings that automatically accompany cognition, such as the feeling of confusion when you haven't understood something.

### **3.3 Metacognitive Knowledge**

Metacognitive knowledge is very broadly conceived, the term covering any knowledge relating to cognition. It can relate to cognitive processes in the self (e.g. I have a terrible memory for faces) and others (e.g. Fred has a problem remembering number sequences), knowledge about cognitive tasks (e.g. that recall is more difficult than recognition) and about cognitive strategies (to remember something, you should rehearse it). The concept includes both procedural and declarative knowledge, it includes self-referential knowledge, specific knowledge of other people, and generalised knowledge about cognitive abilities. Flavell is not concerned to provide a developmental account, but clearly the accumulation of knowledge about cognition is central, both domain general and domain specific knowledge.

Metacognitive knowledge and metacognitive experiences, Flavell (1979) claims, interact with goals and actions (strategies) in "interesting ways". However, he did not advance any speculations as to the nature of those interactions. The goals - the objectives of a cognitive enterprise - and actions (or strategies) - the behaviours employed to achieve the objectives - form the essential framework for the operation of metacognition, but are not in themselves metacognitive.

Flavell (1979, 1981) states that both metacognitive knowledge and experience do not differ from non-metacognitive knowledge and experiences in terms of form or quality, but only in terms of content and function. Thus, they are not 'meta' in any second-order sense. The question then becomes one of whether there is anything to be gained by labelling a certain *domain* of knowledge or experience as 'metacognitive'. It is trivially true that the *content* of knowledge differs between any two domains e.g. a person's knowledge of babies differs in content from their knowledge of computers. Similarly, the *function* of that knowledge differs in a straightforward sense, in terms of the contexts in which the different knowledge bases are useful. The knowledge of computers will not help a woman decide whether her baby is ill enough to call out a doctor. If there is anything special about knowledge of cognition (rather than knowledge of anything else), it must be demonstrated. Many of the researchers who were interested in 'metacognition' seem to be following such lines of reasoning, by looking at the implications of a knowledge of mind, under the 'theory of mind' umbrella (e.g. Flavell 1988, Wellman 1988). 'Theory of mind' will be discussed further in section 3.

If 'metacognitive' knowledge itself is not privileged in any way, it is possible that the processes which use that knowledge may utilise it in a

distinctive way. Flavell mentions 'cognitive monitoring' in this regard, and this process will be discussed further in section 3.4 below.

### **3.4 Metacognitive experiences**

Metacognitive experiences are the feelings that accompany cognition, and, in general, cognitive psychologists have very little to say about feelings and emotions. It is not clear how 'metacognitive experiences' fit in with many information processing theories, but it is not clear that anything is gained by describing them as 'meta'. The feeling of hunger could be described as a 'meta-digestion' experience, but this is not particularly helpful. It is merely an 'about digestion' experience, just as 'confusion' is an 'about cognition' experience.

There is plenty of evidence that children have cognitive experiences before they are able to *use* such experiences to improve their performances. For example, Flavell, Speer, August, and Green (1981) have shown that young children experience puzzlement when asked to build a tower, by an experimenter who gives them only vague instructions. They do not correctly locate their problems as emanating from the speaker's inadequate messages and they are unable to use their 'metacognitive experiences' of uncertainty to improve their performance by asking for clarification (see also Markman 1977, Robinson and Robinson 1977, Robinson 1983). However, this pattern seems to be equally true of other, non-cognitive feelings. Young children generally fail to understand the significance of their feelings. A toddler will become fractious because they are hungry, but will not request food although this is within their linguistic capabilities. They presumably have the unpleasant stomach sensation, but do not know what is causing it or how to deal with it. Here again, there has been no special status demonstrated for 'about cognition' experiences.

The crucial development seems to be in the *understanding* of the experiences. This requires both the awareness of the experience and its connection to the domain specific knowledge which explains the significance the experience.

Merely identifying domains of knowledge and experience as 'meta', as Flavell has done, does not seem to be interesting or illuminating. The concepts described by Flavell could equally well be referred to with the simple adjective 'cognitive' which would mean simply 'about cognition'. Nothing super-cognitive has been demonstrated.

### **3.5 Distinguishing the cognitive from the metacognitive**

"Cognitive strategies are invoked to make cognitive progress, metacognitive strategies to monitor it ... your store of metacognitive knowledge is apt to contain knowledge of metacognitive strategies as well as cognitive ones"

Flavell 1979 (p. 909)

Flavell (1979, 1981, 1987) has argued that it is often difficult to distinguish the cognitive from the metacognitive. This should not be the case if the concept of 'metacognition' was clearly defined, and distinctly different from cognition. Flavell (1987) states that the same activity might be cognitive in one context and metacognitive in another. For example, a cognitive strategy might be to add up a list of numbers to achieve the goal (the total) and a metacognitive strategy would be to add them up for a second time to achieve a total. Brown (1987) provides an example which, she claims demonstrates the interchangeability of cognitive and metacognitive functions. She argues that asking yourself questions about a chapter might serve either

to improve your knowledge (cognitive function) or to monitor it (a metacognitive function).

This lack of clarity indicates, for us, that the cognitive-metacognitive distinction is not a useful one for understanding these strategies. There would be not interchangeability between the cognitive and the supercognitive. The same activity could never be both cognitive and supercognitive, as they would not be part of the same system.

The adding of numbers must always be a cognitive activity, a learned procedure for achieving a goal, the goal being to find the total. This may be supplemented by the additional knowledge that a certain category of addition problems are complex, and are thus prone to errors. It is this *awareness* that prompts the subject to repeat the (cognitive) activity and invoke the additional (cognitive) procedure to check that the totals are the same for both operations. The goal here being to confirm the result. There will be declarative knowledge available within the brain of the proficient arithmetician about the addition processes e.g. that it is prone to error; and that repeating an addition is a good way of checking the result. However, this knowledge is not supercognitive, and not qualitatively different from the basic knowledge of addition. By its very nature, though, it must follow knowledge of addition developmentally: it is not possible to have knowledge about a process when you are not able to use the prerequisite process itself, and to which the former makes reference. This point will be raised again in chapter 9.

### **3.6 Flavell's cognitive monitoring.**

Flavell included the term 'cognitive monitoring' in the title of his 1979 paper, but then failed to describe fully what was meant by it in the text.



The bulk of the paper is devoted to describing the knowledge and experiences outlined above. Cognitive monitoring immediately sounds like a second-order process (although the 'meta-' prefix is *not* used here). It sounds like a monitoring process which operates over cognitive processes. However, Flavell (1979) merely states that cognitive monitoring occurs

"through the actions and interactions among four classes of phenomena:

(a) metacognitive knowledge; (b) metacognitive experiences; (c) goals (or tasks); and (d) actions (or strategies)."

Flavell 1979 (p.906)

This account, unfortunately, provides little explanation of *how* the developing (meta)cognitive knowledge might be used by the monitoring process.

In a later paper Flavell devotes a whole chapter to describing examples of cognitive monitoring (Flavell 1981). However, the 'model' presented simply involves four boxes (relating to the four phenomena in the above quote) with bi-directional arrows linking each one to all the others. This again explains very little. It is clear that all these types of cognition interact, but the model does not explain how they are controlled and co-ordinated, or how they develop.

The question must again be raised as to whether 'cognitive monitoring' is different from 'monitoring' of performance in general. There is clearly an aspect of cognition which controls, directs, and evaluates activity. It has not been demonstrated that there would need to be a different process operating for the domain of cognition.

### **3.7 Concluding summary**

This section has argued that there is nothing essentially 'meta' about metacognition, and that the concept does not further the understanding of 'cognitive flexibility'. The differences between (meta)cognitive knowledge, and (meta)cognitive experiences, and other non-cognitive knowledge and experiences have not been shown to be qualitative, relating only to different domains. The 'cognitive monitoring' process, has not been shown to use (meta)cognitive knowledge in any special way, and may therefore be a general higher cognitive monitoring process.

The term 'metacognition' has largely fallen out of use, current theorists pursuing some of the (meta)cognitive knowledge issues under the 'theory of mind' umbrella. This will be outlined in the next section.

## **4. Metarepresentation and the Development of 'Theory of Mind'.**

### **4.1 Theory of mind**

'Theory of mind' demarcates a body of knowledge about mind, which children acquire at around the age of 4. This knowledge is integrated into a 'theory' which allows the child to reason about things which a younger child cannot (although see Johnson 1988 for arguments against the attribution of theoretical status to early knowledge about mind). The classic task used to identify the possession of a 'theory of mind' is the false belief task. A 4-year-old child with a 'theory of mind' can recognise that another person will hold a false belief, if a situation (e.g. the location of a hidden sweet) changes in that person's absence. A 3-year-old child will typically claim that the absent person will be aware of

the changed location of the sweet, if the child themselves is aware of the change.

The possession of a theory in any domain will allow a person to make predictions and explanations, basically to understand that domain knowledge. It is a measure of the organisation of that knowledge. Olson, Astington and Harris (1988) argue that the repercussions of this new knowledge are so widespread, that developing a theory of mind could be considered to form a stage in cognitive development. The lack of a 'theory of mind' has been used to define autism (Baron-Cohen, Leslie, and Frith 1985). Autistic children with a mental age well above 4-years-old do not distinguish their own beliefs from those of others, and fail on the false belief task. However, the autistic's deficit may be more than the lack of a theory mind. The inability to conceive of other minds may be consequence of earlier, more fundamental developmental problems (see Sheila Spensley 1995 for an alternative view of autism).

It is trivially true, that it is not possible to reason about a domain if you do not have the relevant concepts. 'Belief' is an 'about mind' concept, which requires awareness by the child of mental states. This is what Karmiloff-Smith (1992) has characterised as going beyond *using* knowledge to *reflecting* on knowledge, and is characteristic of many other domains, other than mind. A child will have had beliefs, and operated on the basis of them before she was aware that she had beliefs. She would need to have an awareness of beliefs in herself before she could generalise them to other minds as well.

It is possible that the normal acquisition of the 'theory of mind' could be explained by the same knowledge acquisition and theory development processes as are operative in other knowledge domains.

This argument was made in relation to Flavell's concept of (meta)cognitive knowledge, and is equally applicable here: the knowledge itself is not represented in any qualitatively different way. However, it has been argued that the development of 'theory of mind' relies on the development of a capacity to 'metarepresent'. This approach will be discussed in the next section, to analyse whether 'metarepresentation' is a component of cognitive flexibility.

## 4.2 Metarepresentation

Olson, Astington, and Harris (1988) argue that 'theory of mind' is necessarily a 'meta-representational system'.

"Because these concepts represent such states as beliefs, desires, intentions, and feelings, they constitute representations of representations and in this sense constitute a recursive or meta-representational system."

Olson, Astington, and Harris 1988 (p.3)

This position is argued because verbs such as 'believe' only have a truth value relative to the individual, rather than a truth value in the external world. The truth of the proposition "e.g. there is chocolate in the fridge" is either true or false depending on the state of the external world (and whether someone has got there first). In contrast, the proposition "I believe that there is chocolate in the fridge" is true or false regardless of the state of the world. It refers only to my mental state. This is the philosophical distinction between propositional attitudes/propositional content.

In the 'theory of mind' context, this line of reasoning confuses the representational *format* with the representational *content*. The fact that the *content* of the concepts refers to the mind, does not mean that they

require a qualitatively different format to contain that knowledge. The content is self-referential, but this does not in itself require supercognitive representations. 'Beliefs, desires, and intentions' are representations *about* representations, they do not have to be second order representations *of* representations.

Perner (1991) defines metarepresentation, as the ability to represent the 'representing' relationship. That is, not just to have a representation of an object, but to have a representation of the connection between the representation and the object. This is obviously quite an advanced form of knowledge, but here again, the 'meta' relates to *content* and it relates to a specific knowledge domain.

The child will be aware of the contingent relationship between the personal mental state, and the external state of the world, but there is no need to posit an awareness *that* this is what she is doing. At this stage the child is using a new level of awareness within a domain, that does not mean that we need a different representational system to explain it.

Knowledge about the mind will obviously be crucial to understanding and reasoning in many domains. In order to acquire knowledge about the mind, there must be access to internal mental states, and some basis for attributing these perceptions to a 'self'. Basically, the knowledge acquisition process for knowledge about mind requires access to the contents of mind, i.e. consciousness. However, in terms of creating representations, this process, it will be argued (in chapter 9) is one of observing and encoding in a comparable way (given this access), to the encoding of visual information (given eyes). The representational format of the 'theory of mind' itself, will not differ from theories about other domain knowledge.

### 4.3 Conclusion

Acquiring awareness of the content of mind may be fundamental to the child's relationship to the social world. However, such a shift may be an emergent property of a more general knowledge acquisition process. Nothing has been demonstrated which differentiates this knowledge domain from any other, either in terms of knowledge format or cognitive process. 'Theory of mind' research largely pursues the implications of the content, which is tangential to the aim of this chapter which is searching for difference in representational format and/or cognitive process.

## 5. The Socio-Cultural approach

Vygotsky (1978) originally proposed a theory of the 'internalisation' of psychological processes. Vygotsky views 'self-regulation' as internalised 'other regulation', the processes originally used to control the child's behaviour come to be used for self-control. Higher psychological processes and even consciousness, have their roots in social relations, or as Leont'ev (1981) developed the concept: in activity. The internalisation process is the method by which control and awareness are *created* by the individual.

Underlying this argument is Vygotsky's distinction between elementary and higher cognitive functions. The elementary process are not under conscious control and respond to stimuli from the environment. Higher psychological processes are under voluntary control and are self-regulated. Vygotsky views development, as a shift from environmental regulation to voluntary regulation.

Elementary cognitive processes are automatic, or unmediated. For example, basic perception and memory will be directly stimulated by the environment. There is no way one can refuse to hear or see something or choose not to remember. In contrast, it is possible to refuse to think about something, refuse to solve a problem or refuse to plan. However, part of development is the bringing under voluntary control of parts of the elementary cognitive processes, for example, creating voluntary attention, and logical memory.

The development of regulatory, and higher cognitive process is supplemented with conceptual development. New concepts will allow thoughts which could not have been possible before to be thought, and will bring old concepts into a different light.

"The new higher concepts in turn transform the meaning of the lower.

The adolescent who has mastered algebraic concepts has gained a vantage point from which he sees arithmetical concepts in a broader perspective "

Vygotsky 1962 (p. 115)

From an information processing perspective, this relates to top-down processing, in that additional knowledge will affect what is perceived and encoded.

The development of cognitive flexibility seems to be domain specific in Vygotsky's account (although his theory contains domain general elements as well, e.g. the complex-concept shift).

"consciousness and control appear only at a late stage in the development of a function, after it has been used and practiced unconsciously and spontaneously. In order to subject a function to intellectual control, we must first possess it."

Vygotsky 1962 (p. 90)

The progression from the ability to carry out an activity to the ability to reflect on that activity, is a theme to be taken up with Karmiloff-Smith in the next section.

Consciousness, for Vygotsky, develops in a comparable way to other domains. It is bringing into awareness the functioning of the mind.

"... awareness of the activity of the mind - the consciousness of being conscious."

Vygotsky 1962 (p. 91)

This progression allows for knowledge and functions to be used as tools.

## **5.2 Developmental mechanisms**

Self-regulation emerges through the internalization of social processes. This occurs in the 'zone of proximal development', which is

"the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with peers."

Vygotsky 1978 (p. 86)

In the zone of proximal development a more capable other acts as a vicarious form of consciousness, until the child can master her own action through her own consciousness and control. Once conscious control has been achieved, the function or conceptual system can be



used as a tool. Prior to this, the more capable other performs the critical function of "scaffolding" the learning task which makes it possible for the child to internalise the external knowledge and to convert it into a tool for conscious control.

Wertsch and his colleagues have carried out an experimental study, and various analyses of the shift from other-regulation to self-regulation. Wertsch, McNamee, McClane and Budwig (1980) carried out an experiment with mother-child dyads solving a copying task. The task used in this study provided the basis for a series of analyses presented in Wertsch's subsequent papers (e.g. McClane and Wertsch 1986, Wertsch and Hickman 1987). The copying task involved a truck puzzle with six square cargo pieces. The cargo pieces were of different colours, but were interchangeable as they were all the same size and shape. The task was to complete the puzzle with a particular arrangement of cargo pieces with reference to a completed copy of the puzzle (the model). The truck portion of the puzzle could be constructed without reference to the model. However, to successfully complete the cargo portion reference had to be made to the model, as the cargo pieces differed only in colour. The cargo-copying problem was compounded by the provision of additional redundant pieces consisting of duplicates of all the correct cargo pieces plus red and green cargo pieces (colours not used in the model). Mothers were instructed that the child should complete the puzzle, with the mother providing help whenever she felt the child needed it.

Wertsch et al (1980) video-taped eighteen mother-child dyads split into three age groups: 2:6, 3:6, and 4:6 year-old children. Their interactions were transcribed, and the transcriptions supplemented with

notes of the child's eye gazing, the mother and child's pointing gestures and the mother's and child's handling of the pieces.

Wertsch et al (1980) found no overall difference in number gazes at the model (the strategic component) between age groups. Although when these were subdivided into "self-regulated" and "other regulated" gazes there were significant differences. The gazing behaviour of the 2:6-year olds was significantly more "other-regulated" than the behaviour of either the 3:6- or the 4:6-year-olds. A further analysis of the behaviour following a gaze at the model, indicated that 2:6 year old required more 'other regulation' to achieve a successful piece placement. Three-and-a-half year-olds and 4:6 year olds were more likely to follow a gaze at the model with correct piece placement. These results indicate that only the older children appreciated the strategic significance of the gaze at the model and spontaneously followed it by the complete action sequence culminating in correct piece placement. They also indicated that the older children had extracted the correct information from the model.

The results provide general evidence for a shift from interpsychological regulation to intrapsychological regulation of strategic problem solving with age (Wertsch et al 1980; Wertsch and Hickman 1987). However, no account was given for mechanisms involved, to further the argument that there was a causal connection between mothers' behaviour and children's development. Wertsch looked for these mechanisms in the structure of the mother-child dialogues. In particular he has looked at "referential perspective" (Wertsch 1985).

Wertsch (1985) has analysed the interaction of two mother-child dyads, in detail, in terms of 'referential perspective'. This refers to the

type of linguistic expression used by mothers to successfully refer to an object. The presuppositions of the utterance then reflects the ability of the child. With the older child, the mother's interactions involved strategy dependent referring expressions indicating that the child understood the the strategic component of the task. For the younger child, the use of 'common referring expressions' indicated that the objects were being dealt with in isolation from the task. The difference in perspectives was interpreted as indicating that the model never existed *as a model* for the younger child. The dyad progressed on the basis of simple direct instructions made with no presupposition of the task strategy. In contrast the older child appeared to recognise the role of the model as he produced the correct behaviours following strategy-related utterances.

The examples indicate that adults can manipulate referential perspective to successfully regulate the behaviour of children. This has important implications for studies of the zone of proximal development as both children in this study successfully completed the task with adult assistance, but the level of assistance in each case was not comparable.

Wertsch claims that referential perspective is probably one of the mechanisms involved in the transition from interpsychological to intrapsychological processes. The fact that the adult is able to involve the child in the task at a simple behavioural level, providing non-strategic reference to the objects in the context of the task provides the child with the basis for understanding the strategic motivation (although it is not clear how this is achieved). If adults initially try strategy-based referential perspectives which fail they switch to the simple reference approach, but Wertsch claims (no evidence provided)

they periodically return to try the strategy-based perspective again. This forms an implicit tutorial mechanism for the child's understanding of the strategy. Referential perspectives allow for a range of regulatory levels by adults, right up to referring expressions such as "the next one" which leaves the strategic behaviour totally in the hands of the child. Wertsch also notes that the change from using strategy independent to strategy dependent referring expressions occurs while the task is still being completed with interpsychological regulation. Changes between these levels gradually require changes in the child's understanding of the task and the amount of strategic reasoning the child has to engage in.

While this referential perspective account is plausible and interesting it is not supported by more than anecdotal evidence from two episodes from two case studies. A more detailed within subjects analysis would provide statistical support for his conclusions. His claim about the periodic introduction of advanced referential perspectives into interactions with children who had previously failed with those perspectives was not supported by any evidence, although such evidence would add support to his argument. In particular it would be interesting to look at the ways in which such perspectives were introduced: for example, if a strategy dependent verbal reference was associated with non-verbal deictics, such as pointing to the appropriate piece which might facilitate transition.

### **5.3 Conclusion**

Vygotsky's approach to development emphasises the interactive nature of cognition, an approach which will be seen to be lacking in Karmiloff-Smith's (e.g. 1986) account (see section 6). From a cognitive science perspective, there is little formality in the socio-cultural approach, in

particular the developmental mechanism 'internalisation' is underspecified. It would currently be difficult to produce an A.I. system that was sufficiently 'interactive'. However, there are many insights to be gained from the approach, although interpreting the work from a cognitive science perspective will necessarily involve interpretation<sup>2</sup>. In chapter 7, this approach to development will be studied further, when Isaev's (1985) account of the development of planning is presented and evaluated.

## **6. Representational Redescription**

### **6.1 Introduction**

In this section Karmiloff-Smith's theory of Representational redescription is discussed as the most detailed and formal account of the development of cognitive flexibility. There are similarities between Karmiloff-Smith's account and that of Vygotsky, in that awareness is seen to (effectively) develop within domains. Behaviour occurs first without awareness and flexibility in that domain follows initial successful performance. However, for Karmiloff-Smith this is an issue of representational change, rather than the creation of awareness. In some sense awareness is a function of content.

### **6.2 Karmiloff-Smith's model of representational redescription.**

Representational Redescription (Karmiloff-Smith 1984; 1986; 1987; 1991; 1992; 1994) explains the emergence of awareness through the redescription of knowledge. Awareness is attributed to certain representational formats and redescription between formats is achieved

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<sup>2</sup> This is, of course, a second level of interpretation, in addition to the translation of the work from the original Russian text.

by endogenous metaprocesses. Representational Redescription is not proposed as a complete model of cognitive development, it only explains development beyond successful performance. Karmiloff-Smith's model begins with successful but un-reflective performance, and ends with flexible, reflective performance. (Note however that this limitation to 'post-success' development will be rejected in chapters 5 and 9).

It is rather an isolated theory, as no-one else is concerned to offer a detailed alternative for this specific area of development. However, the theory has been used by others, e.g. Boden's (1992; 1993) account of creativity. Karmiloff-Smith (1992) has also provided a wide range of examples from domains as different as language and physics.

A distinctive feature of the theory is the level of formality with which it has been specified (Karmiloff-Smith 1986). Karmiloff-Smith is one of the few developmental psychologists who has attempted to specify her theory at the algorithmic level (Marr 1982). For this reason the theory forms the focus of this thesis. Karmiloff-Smith (1986) has produced a detailed account, which, it will be argued is flawed in various ways (see chapters, 3, 4, and 5), but it has the merit of being clear enough to be falsifiable. In this chapter the theory of Representational Redescription (RR theory) will be outlined.

### **6.3 Beyond success**

Representational redescription is not proposed as a complete theory of cognitive development, it particularly explains development *after* the child has achieved behavioural success. However, Karmiloff-Smith (1986; 1992) believes it to have general applicability across all domains. The theory suggests that awareness, and the ability to use knowledge flexibly is associated with the level of description of that knowledge.

The child moves from being able to merely perform a task to awareness of, and access to that performance. Endogenous<sup>3</sup> metaprocesses redescribe the knowledge at one level into a more accessible format (Karmiloff-Smith 1986). This redescription is required for the knowledge to be used flexibly, allowing the children to 'operate on their own procedures' (Karmiloff-Smith 1990).

The idea of representational change beyond successful performance is controversial. Most accounts of cognitive development end with successful performance rather than starting there. Clearly, skills develop and improve with practice, but the representational redescription account claims that the identical overt (successful) behaviour can be produced from quite different underlying representations (Karmiloff-Smith 1986). The clearest behavioural support for this claim is the existence of u-shaped behavioural curves in development. U-shaped behaviours (Strauss 1982) are those behaviours which are performed correctly by a child, who subsequently performs them incorrectly before once again producing correct performance. These 'u-shaped' behavioural changes are seen by Karmiloff-Smith (amongst others) as the external manifestations of underlying representational change.

Whilst the existence of spontaneously-occurring u-shaped behaviours may have provided the initial motivation for the model, they are not a necessary concomitant of the process. Representational redescription is presented as applying to 'post-success' cognitive development in general. In the majority of domains the first

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<sup>3</sup> Karmiloff-Smith does not rule out the influence of social processes in development, but argues that it is the internal processes that are crucial to development beyond behavioural success.

representational reorganisation will not have a detrimental effect on performance, and there will be no evidence of a u-shaped behaviour.

Karmiloff-Smith provides the most detailed account of her model in her 1986 paper, and supports it with evidence from linguistic repair data. In chapter 5 when the model is criticised, in theoretical terms, reference will be made to her language acquisition examples. However, for the time being I will concentrate on the model's applicability to non-linguistic domains.

Karmiloff-Smith's model of representational redescription has three phases. Interpreted in terms of U-shaped behaviours these correspond to the three behavioural phases i.e. phase 1 - initial success; phase 2 - performance decrement; phase 3 - new success. Spontaneous U-shaped behaviours are rare, but they are useful for expository purposes. In most domains these three hypothesized phases of representational redescription would not be accompanied by obvious behavioural changes.

Karmiloff-Smith's model is a phase, as opposed to a stage model. Stage models, such as Piaget's, are global descriptions of the child's ability and are age related. The particular stage a child is at is characterised as globally affecting all her activities. Karmiloff-Smith's phases relate locally to specific tasks. The phases are always passed through in a strict order for all tasks, but at any particular age a child will be at different phases on different tasks. Underlying these three behavioural phases are four levels of representation. The first level is the original representation associated with successful performance, and the other three levels reflect repeated redescriptions of the original (Karmiloff-Smith 1986).



Karmiloff-Smith emphasises the distinction between behavioural change and representational change in cognitive development. Other accounts of development (e.g. Marshall and Morton 1978) have taken behavioural success as evidence of underlying competence (in the Chomskian sense) and do not account for a child's development beyond the achievement of successful performance. Karmiloff-Smith (1984, 1986, 1987, 1992, 1994) provides many examples of children developing beyond successful performance, particularly in their linguistic behaviour. Children who successfully used words such as "went" later produce the incorrect forms "go-ed" and "went-ed" before they once again produce the correct word. She argues that competent performance does not necessarily indicate an adequate underlying representation and that, in general, representational development continues beyond the initial appearance of successful behaviour. However, the only *evidence* for the idea of representational development beyond behavioural success (in the form required by the model) is provided by examples of u-shaped behaviours. The claim that this 3-phase process is general to all of cognition seems to be an, as yet, unsupported hypothesis. However, Karmiloff-Smith (1992) has related her model to a broad range of domains, and claims generality.

An example Karmiloff-Smith (1984, 1992) uses to illustrate the model is her block balancing task<sup>4</sup>. This task produces a u-shaped curve in performance in 4- to 9-year-old children. In this task the children were provided with a number of blocks which they were asked to balance on a metal bar. The blocks were of three types, illustrated in figure 1. Type A blocks were symmetrically weighted and balanced in

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<sup>4</sup> The account of the block balancing task provided in the 1984 paper is a concise version of the findings of Inhelder & Karmiloff-Smith 1974.

their centre. Type B blocks were obviously weighted at one end and therefore balanced off centre. Type C blocks were inconspicuously weighted with lead implants, so that they looked like type A blocks, but actually balanced off centre.

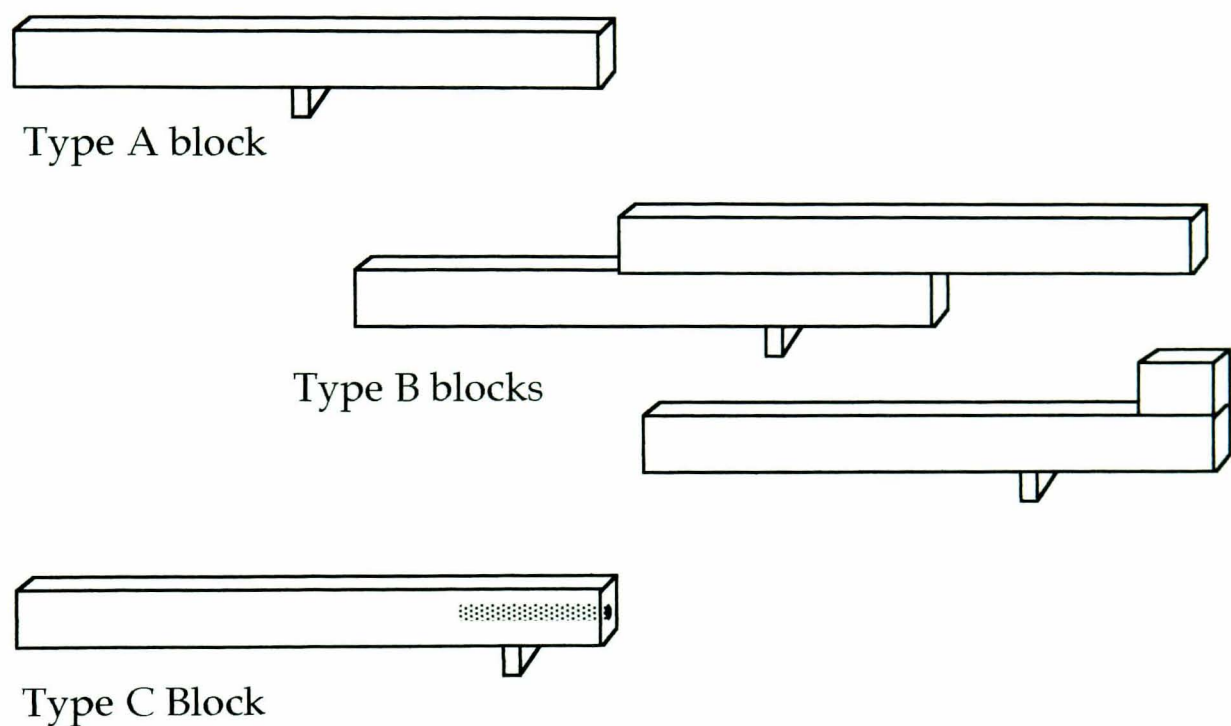


Figure 1. Examples of blocks used in the block balancing task.

Karmiloff-Smith (1984) reports that the youngest children could successfully balance all the blocks, whilst slightly older children failed on all but the type A blocks. The oldest children could again balance all the blocks.

According to the model, the behaviour in the first successful phase reflects data-driven processes. During this phase the child treats each block as an isolated problem and successfully balances the blocks

through a process of positive and negative proprioceptive feedback<sup>5</sup>, moving the blocks backwards and forwards along the bar until balance is achieved. The underlying knowledge is represented as isolated, compiled, procedures. Karmiloff-Smith is not concerned to account for the process by which the knowledge associated with initial success is acquired, she just claims that once acquired it is represented in terms of compiled procedures.

The second phase reflects the involvement of metaprocesses, a purely 'top-down' operation. Children's behaviour in this phase is dominated by a 'theory' that things balance in the middle and phase 2 children are only able to balance type A blocks. They only try to balance blocks at their geometric centres and those blocks that do not balance are discarded as 'impossible' to balance. Children in phase 2 do not use the proprioceptive feedback that had proved successful in phase 1, as they are dominated by their 'theory'. If asked to balance the blocks with their eyes shut children revert to proprioceptive methods, indicating that the performance decrement is not due to a loss of the ability to use feedback mechanisms. In terms of the underlying representation, unconscious 'metaprocedural operators' have been used to redescribe the original isolated procedures. This operation produces additional organisation-oriented procedures which reflect the common components present across procedures. These new procedures may be over-general. Where over-generalisations occur a decrement in performance can be seen and the child's behaviour exhibits a u-shaped growth curve. This behavioural evidence of redescription will not be available for the majority of tasks, where the redescribed procedures continue to produce correct performance in phase 2.

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<sup>5</sup> Proprioceptive feedback involves the use of information directly gained from the movement and orientation of the body.

At the third phase children again manage to balance all the blocks. Initially they try the geometric centre, but then use proprioceptive feedback if this approach does not succeed. Phase 3 may produce similar (or even the same) outward performance as phase 1, but the underlying representations are different. The rigidity of the initial redescription into generalised procedures (at phase 2) is lost as these procedures are modified by external data to cope with exceptional cases in a flexible way. The child's behaviour in this phase is neither dominated by top-down control mechanisms nor environmental stimuli. There is a dynamic interaction between them. At this phase the procedures have been redescribed to allow for conscious access, although maintaining the original code in which the skill was acquired. Procedures may be further redescribed from this original code into an abstract code or "mentalese". This uniform code enables generalisations to be made across codes and allows easy translation into a linguistic code facilitating verbal report. This fourth level of representation will not always occur, and there is no spontaneous behavioural evidence associated with this redescription.

The motivation for representational redescription beyond successful performance cannot be negative feedback as the behaviour is already correct. Although negative feedback may account for development prior to success, Karmiloff-Smith argues, further development must be endogenously motivated. The initial redescription is driven by the goal of

"control over the organization of internal representations"

Karmiloff-Smith 1986 (p. 105)

The internal stability of the successful phase 1 procedures allows the child to become sensitive to competing and/or inconsistent

representations (this process does not imply consciousness). Later redescription is also motivated by the stability of the successful representations, but this time at the metaprocedural level (Karmiloff-Smith 1986).

## 6.4 Conclusion

Karmiloff-Smith considers her account to be a general model of cognitive development following successful performance rather than as a specific explanation of tasks which give rise to u-shaped behaviour patterns. Although, as we mentioned earlier, the only evidence supporting the specific 3-phase-form of the model is provided by the existence of u-shaped behaviours. U-shaped behaviours themselves are controversial: Klahr (1982), amongst others, has argued that they are mere artefacts of the measurement techniques and therefore uninteresting.

To side-step this debate on the status of u-shaped behaviours<sup>6</sup> and to support the claim of generality for her model, Karmiloff-Smith's needs to find supporting behavioural evidence in a task where it would not spontaneously occur. Karmiloff-Smith (1990) has extended her analysis to children's drawings which form just such a domain. In the next chapter we will describe this study and then describe our own experiments which call aspects of her model into question. Representational redescription provides an interesting approach to cognitive development, and it will be argued that it is a more general developmental application than Karmiloff-Smith envisages.

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<sup>6</sup> Karmiloff-Smith has not to our knowledge entered the debate on U-shaped behaviours. She is at pains to stress that her model accounts for more than this limited set of behaviours (personal communication, appendix 1). However, she should perhaps address these issues if they are the motivation for proposing the 3-phases of her model.

## 7. Summary

In this chapter we have introduced the idea of 'cognitive flexibility' which is generally the ability to apply higher cognitive functions, such as planning, to a specific knowledge domain. The chapter began by rejecting the concept of 'metacognition' as a useful avenue to pursue 'cognitive flexibility'. The definition of *what* develops is still somewhat vague, but the chapter described two accounts of proposed developmental mechanisms, the *how*. Vygotsky's account of the internalisation of social process will be pursued in chapter 7, in relation to Isaev's account of the development of planning. Karmiloff-Smith's Representational Redescription theory will form the focus of the thesis, as it is a testable 'Cognitive Science' model.

The RR theory will be explored in more depth in the next 3 chapters. In chapter 3 an experimental study in the drawing domain will question the initial representational format assumed by the RR model, namely that successful performances are represented as compiled procedures. Then in chapter 4 the block balancing task (outlined in this chapter) will be looked at in depth (also described below) and a replication attempt reported. The block balancing task is claimed to illustrate all the hypothesized stages of the RR theory (Karmiloff-Smith 1984), and should provide a sound basis for any reformulation of the RR theory. In chapter 5 the RR model will be evaluated from a theoretical standpoint in terms of its internal consistency and completeness as a formal system.

Throughout the thesis, and particularly in chapter 9, it will be argued that representational redescription is a more general developmental mechanism than Karmiloff-Smith has suggested, although it has to be significantly reformulated to achieve this generality.

## **Chapter 3**

### **Representational Redescription and the lack of evidence from children's drawings**

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#### **Chapter Abstract**

Karmiloff-Smith (1986) has provided a detailed model of Representational Redescription, which explains the development of cognitive flexibility. In a recent paper she has supported one feature of the model: that the initial representations, are compiled procedures, with evidence from a drawing task. She asked children to draw a 'strange man' and argued that young children could not produce any modifications to their man drawings which required them to 'operate on their procedures'. This chapter replicates the difference in modification types between age-groups, but demonstrates that this is not due to a procedural representation. The representation is far more flexible. The explanation for the difference in modification-types is suggested to be explained either by the development of planning or the development of creativity.

#### **1. Introduction**

In the last chapter Karmiloff-Smith's theory of Representational Redescription (RR) was presented and it was shown to provide the most formal account of the development of cognitive flexibility. This chapter

will look in detail at some of the data she has used to support one aspect of the model, that is, the initial representational format. Karmiloff-Smith's most recent experimental work concerns children's drawing (Karmiloff-Smith 1990) and in this chapter that data is examined and some studies presented which fail to support her analysis.

## **2. Evidence from children's drawing**

Karmiloff-Smith's (1990) study of children's drawing addresses only one part of her model, specifically, the issue of representational format. The study sought to show that the representations associated with initial successful performance, i.e. phase 1, were isolated, compiled, procedures. The task involved asking children to draw a man and then "a man that does not exist" (also a house / "house that does not exist" and an animal / "animal that does not exist"). The rationale was that the ability to draw "a man that does not exist" requires children to operate on their representations to make some kind of alterations to their usual drawing of a man. In terms of the Representational Redescription model, this kind of flexibility does not emerge before the initial procedural representation has been redescribed twice, i.e. in phase 3

In keeping with her model Karmiloff-Smith (1990) took 'behavioural mastery' as the starting point and looked at children between the ages of four and ten. By the age of four to five children can normally draw a simple house and man. She hypothesized that these early competent drawings are represented as "compiled and automatised" procedures (Karmiloff-Smith 1990, p. 63) that can be run easily and consistently by the young child. The child has no access to the constituents of the procedure and the procedure can only be run in its entirety (consistent with the notion that it is compiled).



At this level of representation children supposedly experience difficulty with the task of drawing "a man that does not exist", due to the fact that "they are forced into operating in some way on their internal representations" (Karmiloff-Smith 1990, p. 61). Almost all the children she tested were able to complete the task, but the 4-6 year old children fulfilled the task requirements in a significantly different way to the 8-10 year olds. The younger children were only able to modify their drawings by altering the shape of elements, the overall shape of the outline, or by omitting elements. Karmiloff-Smith argued that at the first level of procedural success children can only execute a complete drawing procedure (composed of a number of elements) and then stop. Where omissions were made Karmiloff-Smith "asserted with some assurance" (Karmiloff-Smith 1990, p. 66) that these must have been made at the end of the sequence, i.e. the procedure had just been prematurely terminated, omitting the final element. However, this claim was only made on the basis of the finished drawings and a few unsystematically collected notes. In contrast, the eight to ten year olds produced all these types of modifications and, in addition, were able to produce variations that involved interrupting their procedures, such as deleting elements in mid-sequence, moving or transposing elements and adding additional elements (either from the same category, e.g. adding extra arms or legs to a man, or cross-category, e.g. adding wings to a house).

In a subsidiary experiment Karmiloff-Smith countered the possible claim that this age difference could have been caused simply by a lack of inventiveness on the part of the younger children. She asked eight 5-year olds to draw "a man with two heads" and "a house with wings". Seven of these children were apparently unable to draw "a man with two heads", and were only able to copy an example slowly and

laboriously. This tortuous success was only achieved, Karmiloff-Smith claims, by creating a completely new procedure <sup>1</sup>. Children were successful in drawing "a house with wings" as this could be achieved by adding wings to a completed house procedure, while the man with two heads supposedly involved interrupting the drawing procedure after the production of the first head to repeat the head drawing phase.

### **3. Drawings are not compiled procedures.**

By using the computational metaphor of "compiled procedures" (1990, p. 62) Karmiloff-Smith is making very strong and specific claims. A procedure is a sequentially fixed series of operations. A compiled procedure is a procedure that has been re-coded (for speed of execution) in such a way that there is no access to the constituent parts of the original procedure. The compiled procedure forms a new unanalysable whole (in a lower level code) which can only run in its entirety. The constituents of the original procedure do not exist as units within the new compiled procedure.

The modifications that Karmiloff-Smith found in the 4-6 year old children's drawings are not consistent with the analogy of a compiled procedure. These children were able to change the shape of elements which implies that the elements were accessible at some level, to be modified. This would not be the case with a compiled procedure. Similarly, deletion of an element, even if it is only the last element in the sequence, presupposes the existence of identifiable elements. The un-insightful interruption of a compiled procedure would not necessarily leave the picture cleanly missing one complete element.

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<sup>1</sup> It is not clear from the model what this 'creating a completely new procedure' means, but we will return to this point in chapter 3.

The procedure could as easily be terminated halfway through drawing a leg, for instance, although this kind of modification was not reported.

It is not essential to Karmiloff-Smith's model that the procedures are compiled, so this issue will be dropped in favour of testing the weaker claim that drawings are (un-compiled) procedures. This leaves the predictions of strict ordering in the production of elements, and the non-interruptable nature of the execution of the procedure.

#### **4. Experiment 1: Are drawings procedures?**

It is possible to test the hypothesis that 4-6 year old children execute procedures when they draw stereo-typed objects. If the hypothesis is to be supported the children must consistently produce all the components of all their drawings of a particular object in a strict order. For example, if a child draws a man in the sequence: head, face, hair, body, legs, arms, then for *every* man drawing that this child executes, these elements must be produced in that same order. If children do not produce exactly the same set of elements in each drawing the procedural account could be taken to apply only to the 'core' aspects of the drawing. In this case any non-essential modifications, such as hats, must be made independently of the execution of the main procedure. That is, after (or before) all the core elements have been produced in their strict sequence. Children should be unable to add new constituents or non-core elements in the middle of their procedures.

Karmiloff-Smith (1990) did not record the order of production of elements within the children's drawings, or routinely note whether omissions were made at the end of the sequence. These predictions can be checked with a simple replication of her experimental task of

"drawing a man"/"drawing a man that does not exist" and consistently noting the order of production of elements.

A further prediction of the procedural account is that the execution of a procedure should be un-interruptable. Karmiloff-Smith supported this aspect of the procedural account with the claim that young children did not produce any modifications of their drawings which involved interrupting their procedures. She argued that all the modifications they made *could* have been made at the end of a drawing. However, the "drawing a man that does not exist" task is complex and involves more than just the interruption of a drawing procedure. The un-interruptable nature of drawing procedures could be demonstrated more clearly with much simpler interruptions.

If, as Karmiloff-Smith claims, 4-6 year old children cannot interrupt their procedures then *any* disruption to the execution of their drawing should force the child to start again. A simple interruption was created in my experiment by knocking a jar of pens onto the floor and asking the child to help retrieve them. If young children have absolutely no access to their 'procedures' then this interruption should force them to restart their drawings.

For children to insert elements into their drawings they have both to suspend their 'procedure' and to insert something new. It is possible that children might be able to re-start a procedure in the middle before they could alter it to insert an additional element. That is, they might succeed with the simple interruption task before they could succeed with Karmiloff-Smith's more complex task.

The concept of a "man that does not exist" would involve more, cognitively, than conceptually simpler modifications. If the procedural

account is to be supported, asking children to make a conceptually congruent modification should prove just as difficult as the "man that does not exist" task. However, the actual change would not have to be invented by the children. This distinction was tested by asking the children to draw "a man with a beard", a conceptually congruent modification which is outside their normal stereo-type. If 4-6 year old children do not have the ability to modify their procedures they should only be able to succeed on the 'beard' task by adding a beard to a completed man.

To summarise, the following experiment involves a replication of Karmiloff-Smith's 'draw a man'/'draw a man that does not exist task' with two additional conditions: draw a man (interrupted) and draw a man with a beard. This allows the order of production of elements to be analysed across four examples of a drawing of a man. If the drawings are produced by executing procedures, then all the elements common to all the pictures should be drawn together, in precisely the same order. Further predictions would be that a simple interruption should disrupt young children's performance and that, in their drawings of bearded men, the beard should always be drawn last.

#### **4.1 Subjects**

Twenty-eight children from Bozeat Primary school (Northamptonshire) and Olney First school (Buckinghamshire) were tested. Their ages ranged from 4 years 8 months to 9 years 4 months. There were 16 children in the younger 4-6 year-old group (mean age: 5:8), and 12 in the older 7-9 year old age group (mean age: 7:11).

## 4.2 Procedure

The children were tested individually in a private room. They were initially presented with an A4 sheet of paper and asked to select a pen from a plastic jar containing twelve pens.

The children were given three drawing tasks containing the four experimental conditions. In the first task children were asked to draw a picture of two men. They were allowed to draw one man without distraction (simple) and were interrupted in the middle of executing the other drawing (interrupt). This interruption involved being asked to help pick up the jar and pens that the experimenter had 'accidentally' knocked onto the floor. This invariably involved them leaving their seat and crawling on the floor. The interruption was not specifically timed but occurred when the experimenter judged that a child was in the middle of her drawing. The task was not sub-divided into two tasks of drawing a single man to avoid asking children to repeat a task that had already been completed satisfactorily. In the second task children were asked to draw a man with a beard. In the third task the children were asked to draw a "man that does not exist". Several different phrasings were used to enable children to understand what was required: "a strange man", "a man with something funny/odd about him", "a make-believe man"; "a man you invent"; "a pretend man"; "a man we have never seen before". Subjects were asked to describe their man when it was completed to ensure that all their modifications were identified.

The order of presentation of these three tasks was randomised and within the "draw two men" task the order of 'simple' and 'interrupt' conditions was also randomised.

The order of production of elements was noted whilst the child was drawing and their performance was video-taped. The notes were cross-checked with the video-tapes to ensure accuracy.

### **4.3 Results and Discussion**

None of the children showed any difficulty in recommencing their drawings following a simple interruption, they immediately picked up where they had left off, without hesitation. Two children were not interrupted because they did not draw the two men in strict sequence. One girl (5:1) drew the head and face of the first man, then drew the head and face of the second man before returning to complete the first man and then completing the second man, effectively interrupting her own 'procedure'. Similarly, a boy (5:7) was not interrupted after he began by drawing the two heads.

None of the children had any problems drawing a man with a beard. All but two of the children drew the beard in conjunction with their drawing of the face (that is, either immediately before, immediately after or in the middle of drawing other facial features). The two children who did not draw the beard along with the face did leave the beard until the end, but these were not the youngest subjects as Karmiloff-Smith would have predicted. One of them (5:11) paused for an extended period while drawing the face, asked "Shall I do a mouth?" and then decided to postpone the problem. The other (9:2) finished his drawing, turned to look at the experimenter, then, with a cry of "oh!", appeared to remember that the man should have had a beard.

Drawing a 'man that does not exist' did prove more problematic. Many of the younger children had difficulty understanding what was required of them. A number of subjects asked questions such as "what

do you mean?" and "what has to be strange about him?" Only one subject (5:10) refused even to try the task, but three children (5:4, 5:10, 6:0) failed to modify their drawing in any way, and then refused to comment on their drawings. These cases will be discussed further in section 9. Children also seemed to latch on to specific words or phrases in the instructions and a number of subjects drew "funny" modifications such as funny faces and funny hats.

Karmiloff-Smith's categorisation of the modifications children made to their drawings was based on the analysis of the finished drawings. The changes children made in the present study were not always obvious from the finished product. Nine subjects did not modify their drawings in ways that would have been obvious from just viewing the final drawing. For example, figures 2 and 3 show drawings of "men which do not exist" which, without the child's explanation, could be mistaken for 'normal' men. All the drawings of 'a man that does not exist' were grouped using Karmiloff-Smith's categories, where possible. For example, Ian's drawing in figure 3 above was categorised as having changed the shaped of the mouth. The categories were: deletion of elements; changing shape of elements; changing shape of whole; changing position or orientation of elements; adding new elements from the same or cross-category. No drawings fell into the 'changed shape of the whole'<sup>2</sup> category, and there was only one cross-category addition so the two categories of adding new elements were merged. The results are shown graphically in figure 4.

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<sup>2</sup> This difference between the data and Karmiloff-Smith's original study may have been due to the restriction of the present study to the 'draw a man' task. It is not clear how 'changed shape of whole' applies to a man, it may be more applicable to the house drawing version.



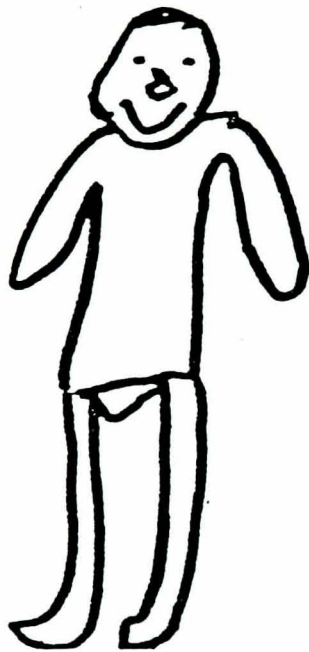


simple



man that does not exist:  
"Jason Donovan"

Figure 2. Idiosyncratic drawing of a "man that doesn't exist". Daniel 5 yrs 11 mths.



simple



man that does not exist:  
"Its sunny outside and he's not smiling"

Figure 3 Idiosyncratic drawing of a "man that doesn't exist". Ian 7 yrs 7 mths.

Analysis of the results in terms of the modification-types made by the two age groups clearly replicates Karmiloff-Smith's (1990) results. Changing the shape and size of elements, was found right across the range of subjects ( $n = 11$ ). However, all except one child (7:7) made their modifications 'mid-procedure'. Deletion of elements was also found across the age range ( $n = 7$ ), but with all of these omissions being made mid-procedure (subjects usually indicated to the experimenter when something was being omitted, e.g. by looking at the experimenter and giggling). Only the older subjects inserted extra elements ( $n = 3$ ), and only one child (9:1) introduced a 'cross-category' element (pig's trotters for arms). Only one child (8:3) changed the position of elements by transposing the nose and mouth.

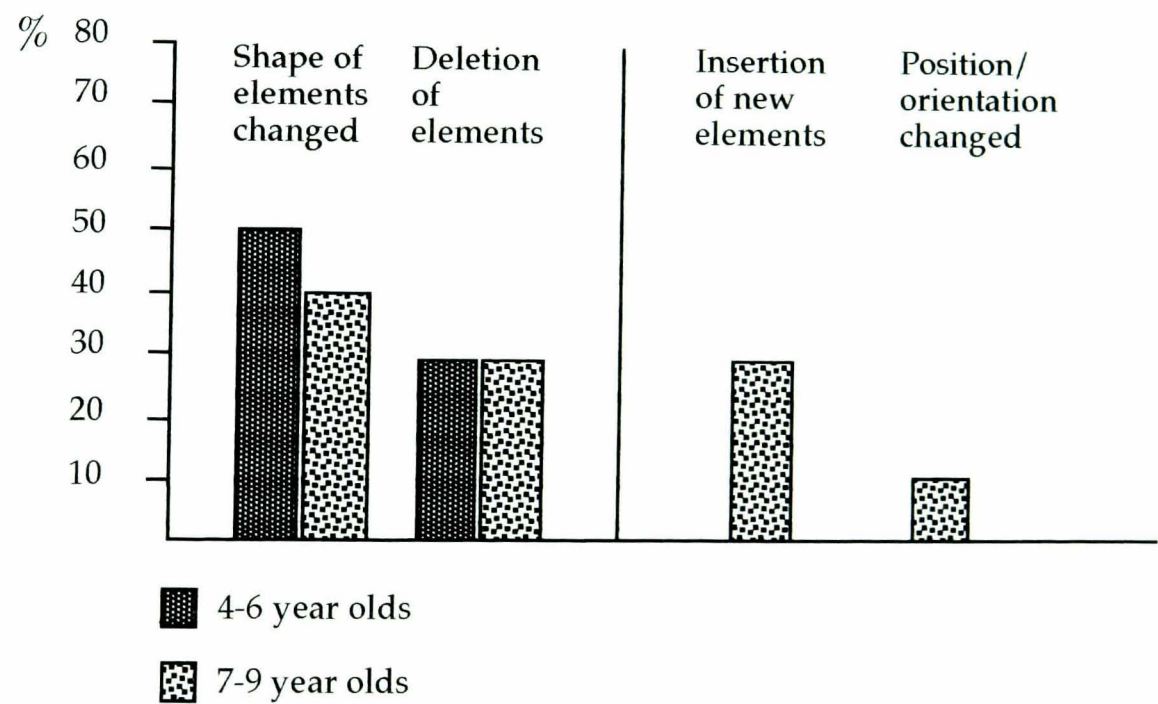


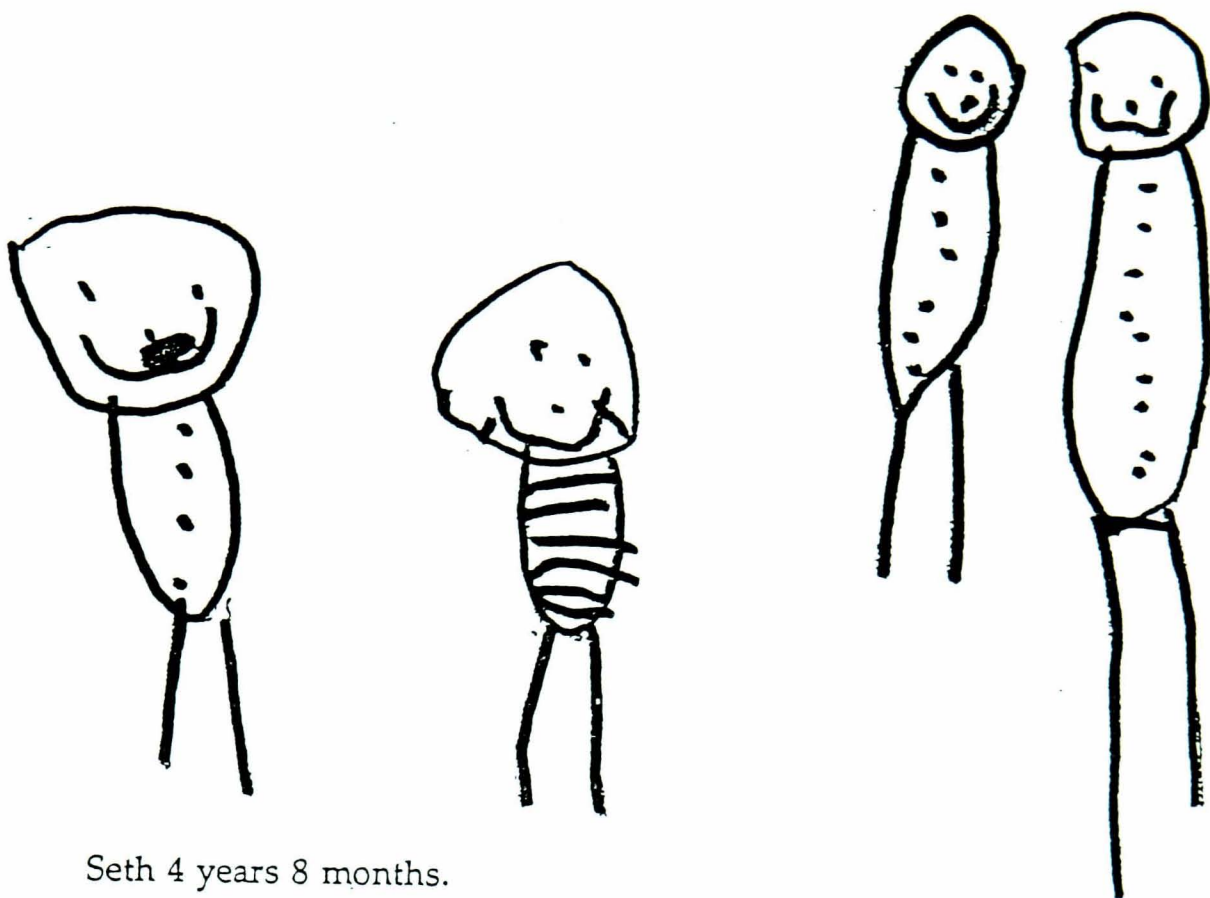
Figure 4. Types of modifications made to drawings

In the critical 4-6 year-old age group twelve of the sixteen children (75%) made modifications to their drawing of a man in the "man that does not exist" condition. All but one of these made their modifications

in the middle of their 'procedure'. This supports the results from the 'beard' condition, showing that young children *are* able to interrupt their 'procedures'. All the 4-6 year-old children produced at least one modification (either the beard or their 'strange' modification) 'mid-procedure'.

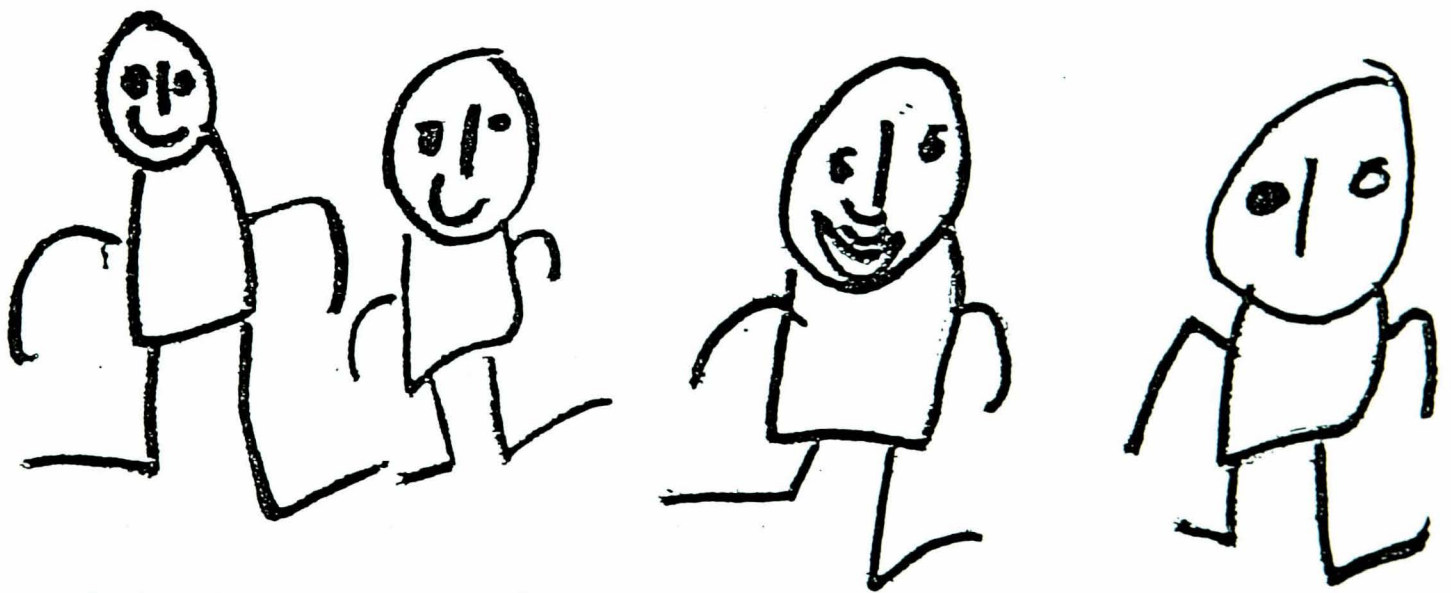
The children did not produce an identical set of elements in every drawing, so the order of production of elements was analysed for just the core components. Core components were defined for each child as those elements which were produced in all four drawings. So, for example, if feet were only produced in three of the drawings they were not taken to be core components. However, if buttons were added to all drawings these were seen as 'core' see figure 5 for an example. The definition of 'core' has been criticised because it includes elements like buttons, which are not conceptually 'core' (Karmiloff-Smith, personal communication - in appendix 1). This definition was adopted because there was no suggestion that the contents of the 'procedure' should be the same across individuals. This formula was believed to allow for individual differences in production across age groups, by accepting what was apparently 'core' to that individual.

The order of production of 'core' components, ignoring non-core components, was then compared across drawings. Although 21 of the 28 children consistently started by drawing the same component (usually the head) in each of their drawings, only three subjects went on to draw all the common components in the same order in each drawing and only one of these was in the 4-6 year old age group. Typically, a child would add the feet as the last element in their first drawing and then produce them in conjunction with drawing the legs in all subsequent productions. Again, these results do not support a



Seth 4 years 8 months.

<u>beard</u>	<u>strange</u>	<u>interrupted</u>	<u>simple</u>
<i>head</i>	<i>head</i>	<i>head</i>	<i>head</i>
<i>face</i>	<i>face ("funny mouth")</i>	<i>body</i>	<i>face</i>
<i>beard</i>	<i>body</i>	<i>legs</i>	<i>body</i>
<i>body</i>	<i>stripes on body</i>	<i>face</i>	<i>legs</i>
<i>legs</i>	<i>legs</i>	<i>buttons</i>	<i>buttons</i>
<i>buttons</i>			



Christopher 5 years 0 months.

<u>simple</u>	<u>interrupted</u>	<u>beard</u>	<u>strange</u>
<i>head</i>	<i>head</i>	<i>head</i>	<i>head</i>
<i>face</i>	<i>face</i>	<i>face</i>	<i>face (no mouth)</i>
<i>body</i>	<i>body</i>	<i>beard</i>	<i>body</i>
<i>legs</i>	<i>arms</i>	<i>body</i>	<i>legs</i>
<i>arms</i>	<i>legs</i>	<i>legs</i>	<i>arms</i>
		<i>arms</i>	

Figure 5 Example of the analysis of drawings into core components for production order comparison 'Core' components in italics.



To summarise, there was no evidence to support Karmiloff-Smith's hypothesis that young children are executing a simple procedure when they are drawing a man. The evidence from the finished products replicates Karmiloff-Smith's results, but by looking more deeply at the production processes it can be seen that the procedural explanation cannot be supported.

## **5. Experiment 2 - 'Behavioural success' in drawing**

A possible criticism of the previous study would be that the subjects tested in this experiment were more advanced than those studied by Karmiloff-Smith (although they were the same chronological age). That is, they could already have progressed beyond phase 1 procedural representations. So, in this study experiment 1 was extended to a group of younger children. This highlights a different problem with Karmiloff-Smith's account: defining what constitutes 'behavioural success' in drawing. This is a problematic issue in many other tasks as well, and will be discussed further in chapters 4 and 5.

Karmiloff-Smith's theory crucially explains representational development beyond 'behavioural success'. However, it is not obvious what constitutes 'success' in the drawing domain, unlike the block-balancing task where a child either could or could not balance a block. Karmiloff-Smith (1990) does not define 'success' or 'behavioural mastery' beyond the "capacity to draw familiar objects with automaticity" (p.60). If 'successful' drawing of a man is taken to be a recognisable likeness of a specific individual, then 'success' is achieved by only a minority of adults. If 'success' is taken to be the point at which others (adults) spontaneously recognise that the marks on the paper represent a man, then this is achieved by children younger than those

studied by Karmiloff-Smith. The definition of 'success' does not include any characteristics of the finished drawing. In the previous studies two of the children did not include arms on any of their drawings, one did not draw a body for any of her men and none of the 4-6 year olds consistently drew a neck. However, they all produced drawings on request and thus perhaps fulfilled the 'automaticity' criterion.

Three year olds commonly produce identifiable 'tadpole' people. Most children do produce tadpoles, although the stage may last only days or a matter of months (Cox and Parkin 1986). Tadpoles may simply comprise of a head with two stick legs, however the intention to depict a person is clear. In terms of communication, they are 'successful'. Initially, the tadpole formalism may not be produced consistently 'on demand', and thus may fail to fulfil Karmiloff-Smith's 'automaticity' criterion. However, Karmiloff-Smith does not make any attempt to define a criterion for 'automaticity', and it is possible that the initial 'success' in figure-drawing, represented by unanalysable procedures, occurs earlier in development.

There are reasons to hypothesize that 'automaticity' might occur at this earlier stage. Previous research has indicated that there may be an atypical rigidity in representation at the tadpole stage. There is also some evidence of a 'u-shaped' performance on related tasks suggesting that the tadpole stage might be associated with the representational change that Karmiloff-Smith is looking for. Cox and Parkin (1986) have argued that tadpole drawers are resistant to attempts to improve their drawings, and Taylor and Bacharach (1982) have shown how the tadpole representation dominates the child's perception of schematic figures.

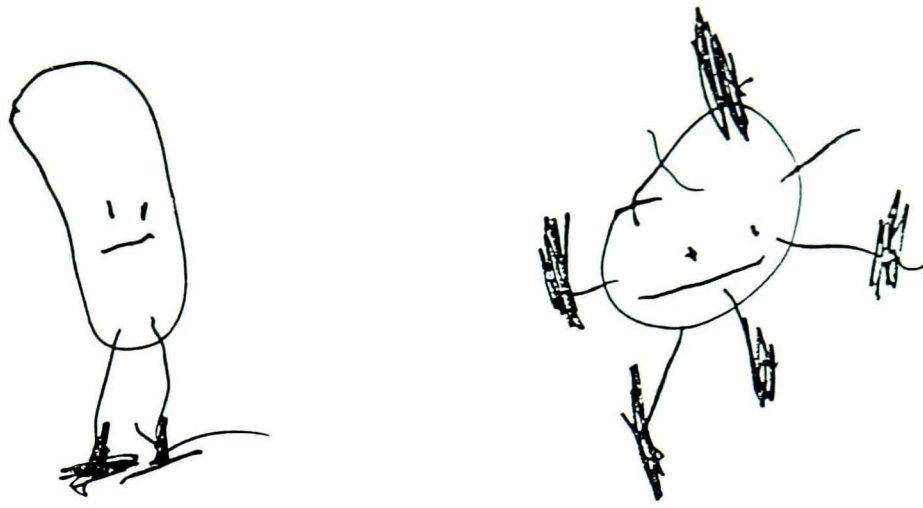


Figure 6. Examples of 'tadpole' people (Lucy, aged 3:2)

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Cox and Parkin (1986) tried to improve the productions of pre-representational drawers (2:0 - 4:11) by decreasing the task demands. They identified five (age-related) categories of children based on their free drawings: those who produced (a) scribbles; (b) distinct forms; (c) tadpoles; (d) transitional figures; and (e) conventional figures. They tried to get children to improve on their free-drawing category with three tasks designed to remove problems of recall. The tasks were: (a) to copy a conventionally drawn figure (figure 7); (b) to assemble a jigsaw of simple pieces (figure 7); and (c) to draw from a dictation of bodily parts.

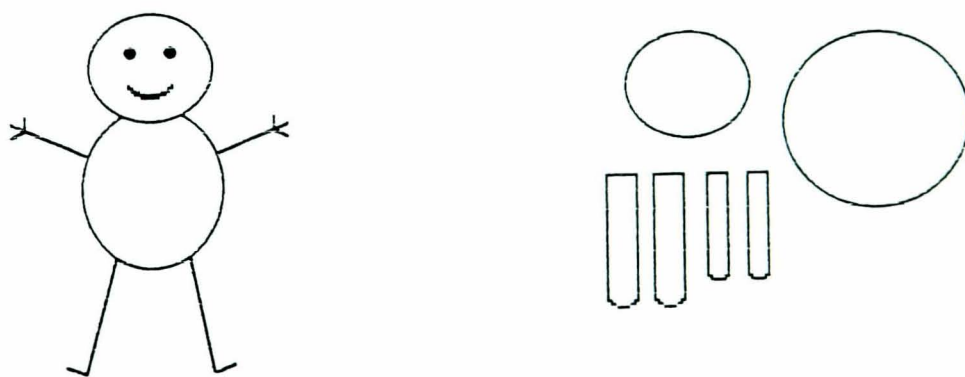


Figure 7. Pre-drawn figure for copying task, and jigsaw pieces for jigsaw task (Cox and Parkin 1986)

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Cox and Parkin (1986) did find that whereas most of the children improved on at least one of these tasks, only 33% of the tadpole and transitional drawers improved on any of the tasks. They concluded that

whatever the representation is underlying the production of tadpoles, it seems to be a stable and resistant form.

"It seems likely that as children develop a system of formulas and rules for representing information in drawings, other cognitive processes might be affected, as suggested in theories proposed by Arnheim (1974) and Harris (1963)."

Taylor and Bacharach 1981 (p. 373).

Meili-Dworetski (cited in Taylor and Bacharach 1981) found that children who could not yet produce representational drawings could name more body parts than children who drew tadpoles.

Taylor and Bacharach (1981) argued that the child's metaknowledge for drawing humans interferes with their ability to name body parts, such that they named only the parts they represented in their drawings. They presented children with three drawings characterising three levels of children's figure drawing: (i) a tadpole; (ii) a figure with a small body, and arms extending from the head; (iii) a figure with the same proportions as figure (ii) but with the arms correctly located.

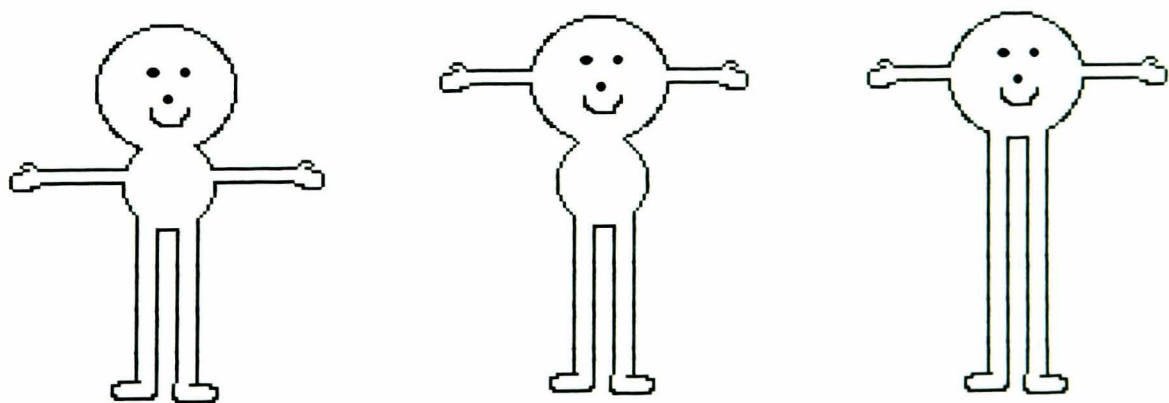


Figure 8 Drawings presented for preference decision (Taylor and Bacharach 1981)

Children were first asked to select the figure that looked most like a real man and then they were asked to draw a picture of a man, using the most accurate representation as a model. They classified children's



productions into three categories: (i) abstract (scribbles); (ii) tadpoles (no body); and (iii) complete (with body). They found that the selection of a figure was significantly associated with the child's type of drawing production. On closer examination it was shown that the selection behaviour of abstract and complete drawers was comparable (the majority selecting the most complete figure) while the largest proportion of tadpole drawers selected tadpoles as the best example.

To test the hypothesis that children younger than those previously tested, may operate with procedural representations, experiment 1 was repeated with younger subjects.

### **5.1 Subjects**

Eight children aged between 3 years 6 months and 4 year 11 months (mean = 4 years 4 months) were tested. They all attended a creche on the Open University campus (Buckinghamshire).

### **5.2 Procedure**

As experiment 1.

### **5.3 Results and Discussion**

The youngest three children did not produce recognisable men on each of the trials, so could not be said to have achieved the necessary consistent behavioural success. For the older children the results were similar to those of experiment 1. Only one of the children exhibited the same production order for the common elements in all of her drawings, and this child produced the beard in the middle of this sequence. All the children inserted either the beard or their 'strange' element mid-procedure. There is again no evidence of a procedural representation.

There was also evidence of spontaneous metacomments made by these children who seemed to be very self critical, and sure of what they were and were not capable. For example, "I can't draw men, only women", this being prompted by an inability to draw short hair. "I can't draw one of those on top of that" on having drawn a line (body?), referring to problem of situating a circle (head?) on the top of it. There was also a level of ongoing criticism of their production: "That looks like his head" on having drawn a rather rounded body. Far from executing an unanalysable procedure children were critically evaluating every stage.

## **6. Experiment 3 The effect of imagination**

Karmiloff-Smith's account of children's behaviour on the drawing task cannot be explained in terms of the representational component of her model. Another explanation must be found for the highly significant difference between age groups in the types of modification children made to their drawings. As was mentioned earlier, Karmiloff-Smith has argued that this result was not due to a lack of imagination. She claimed that 5 year old children were unable to draw a man with two heads because this involved interrupting a procedure. In theory, the children who succeeded on the "house with wings" task by adding wings to a completed house could just as easily have added a second head to a completed man, but clearly they did not do this.

Karmiloff-Smith's explanation is not satisfactory, but the replication of the difference between age groups leaves an unanswered question. Are young children *incapable* of producing certain types of modification to their stereotyped drawings? To answer this question children were asked explicitly to draw men with each of the modification-types

Karmiloff-Smith had identified in spontaneous productions. To make the instructions absolutely clear the first eight children were briefly shown an example drawing. It was stressed that they did not have to produce the modification shown in the example, but that they were free to make up their own variant. As this visual example seemed superfluous, a further seven subjects were not shown the visual example although the same example was presented verbally.

## **6.1 Subjects**

Fifteen 4 to 6 year old children (not involved in the previous studies) were tested individually in a private room. The first eight attended Bozeat Primary school (Northamptonshire) and the other seven attended Olney First school (Buckinghamshire). Their ages ranged from 4 years 10 months to 6 years 2 months (mean age: 5:8).

## **6.2 Procedure**

Subjects were asked to make a series of six drawings starting with the simple drawing of a man to provide a baseline for comparison, and to allow them to relax and succeed at a task. Children were then asked to draw a series of 'strange' men with very specific modifications. After each instruction the first eight children were shown an example drawing, which was removed before they started their drawing. A further seven children were given the example only verbally. All the children were told that they could think of their own variant or reproduce the example as they wished. The categories and examples, in order of presentation, were:

- (i) a man with some part of his body the wrong shape (e.g. a man with a square head);
- (ii) a man with too many of something (e.g. a man with two heads);

- (iii) a man with something missing (e.g. a man with no arms);
- (iv) a man with some part of his body in the wrong place (e.g. a man with legs coming out of his arms);
- (v) a man with some part replaced with part of an animal (e.g. a man with wings instead of arms).

Subjects were encouraged to describe what they were doing while they were performing the task or to describe their "strange man" after they had completed it.

The order of production of elements was noted whilst the child was drawing and their performance was video-taped. The notes were cross-checked with the video-tapes to ensure accuracy.

### **6.3 Results and discussion**

The children in this experiment were clearly happier with these tasks than the children presented with the less specific "draw a man that does not exist" task. The younger ones particularly found the requests highly amusing, indicating that they had not previously thought of making such modifications themselves. The youngest four children (4:10 - 5:3) did exhibit some lack of imagination in that they simply reproduced the examples given. Older children produced their own manipulations and tended to make multiple alterations to their drawings rather than being satisfied with the minimum, e.g. adding an extra head, two extra arms and an extra leg. Drawing sequence was again analysed and it was found that all the children made some of their modifications mid-procedure.

Only one child, Michelle (5:1) failed on any of the tasks. As the worst case her performance will be described in detail. Her drawings are

reproduced in figure 9 overleaf. Michelle was easily able to perform the first two manipulations, changing the shape of an element - she drew a man with a square head and triangular arms; and omitting an element - she drew a man with a missing arm and missing buttons. This is consistent with Karmiloff-Smith's predictions for her age group. She had problems with the man with two heads task, and the finished result shows, as Karmiloff-Smith would have predicted, that attempting to produce a man with two heads resulted in a drawing of two men. Michelle showed a tendency to copy the example given, in this case a man with two heads, but the task requirements were simply to draw a man with too many of something. Although she may have failed in an attempt to draw a man with two heads, she actually succeeded on the task by adding an extra set of arms to both men. When asked to describe her finished drawing she made no mention of the two heads, nor did she think that she had drawn a single man:

E: "That's lovely. Can you tell me about it?"

Michelle: "He's, they've only got two arms and no legs"

The order of production of the elements in this drawing was. A head and a body, then second head followed by a second body. The face was then completed on the second body and four arms were added to it. She then returned to the first body drew the face and then four arms on it. This does not fit with Karmiloff-Smith's idea that having completed a normal man, a child draws a second head and then, having started a procedure is compelled to complete a second man. Michelle's drawings were executed in parallel which indicates that she was not just running a procedure. The problems she had with her production may have been due to a lack of planning. The body element needed to be enlarged to allow for the attachment of an extra head, and having drawn the extra

head Michelle was faced with a problem of attachment to the pre-drawn, but inappropriate body. This problem is aggravated by the fact that her standard 'successful' drawings of men did not include the drawing of necks - the simple solution to the attachment problem. However, these potential explanations are speculative - her production was fluent, providing no behavioural evidence of pauses in production, and as her drawing was video-taped over her shoulder there is no data from facial expressions.

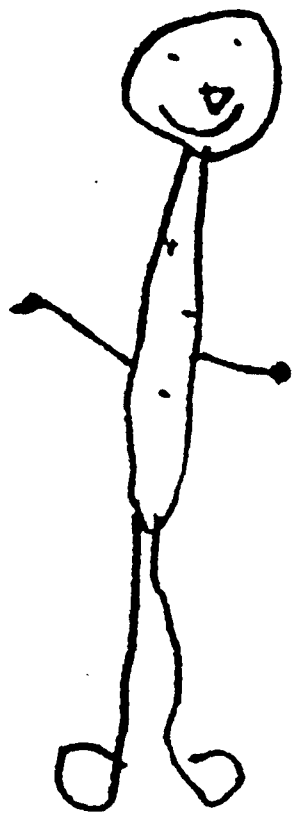
Michelle completely failed on the relocation task. Here her production order was: head; body; legs; arms; face; hair; displaced legs. Her post-drawing comments indicated that she realised her problem, but again, it could be argued, that this was due to a lack of planning: when she came to draw the misplaced legs she found that she had already drawn some in the correct location.

E: "Can you tell me about that man?"

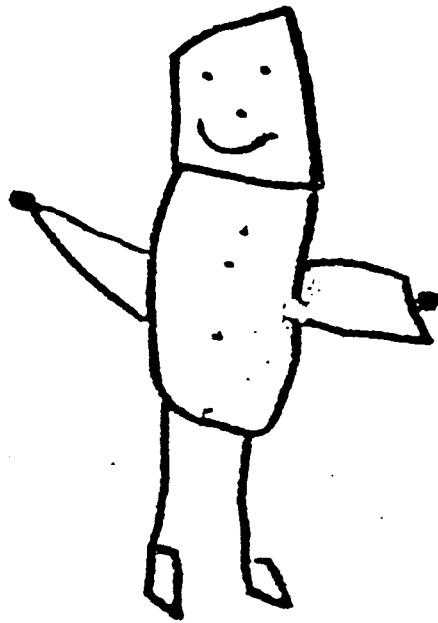
Michelle: "He's got some legs, but he's lost some."

Michelle's final drawing, which on the procedural account should have been of comparable complexity to the two problematic drawings, was executed perfectly. The order of production was: head; face; body; wings; legs; hair; buttons. It is important to note that the wings were not the last element added, and that they replaced the arms rather than being added to a completed man which would include arms.

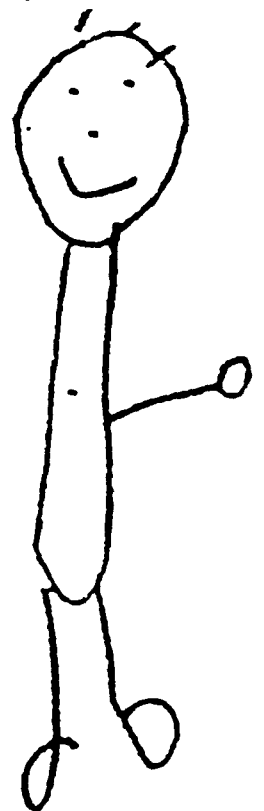
Two children had to restart one each of their drawings, although they were successful on the first attempt with all their other drawings. Andrew (4:10) had to restart his drawing of a man with wings after his



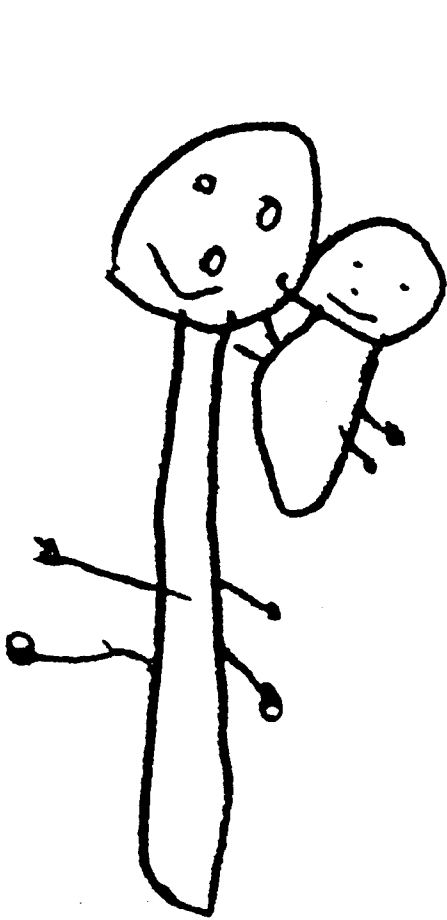
(a) simple



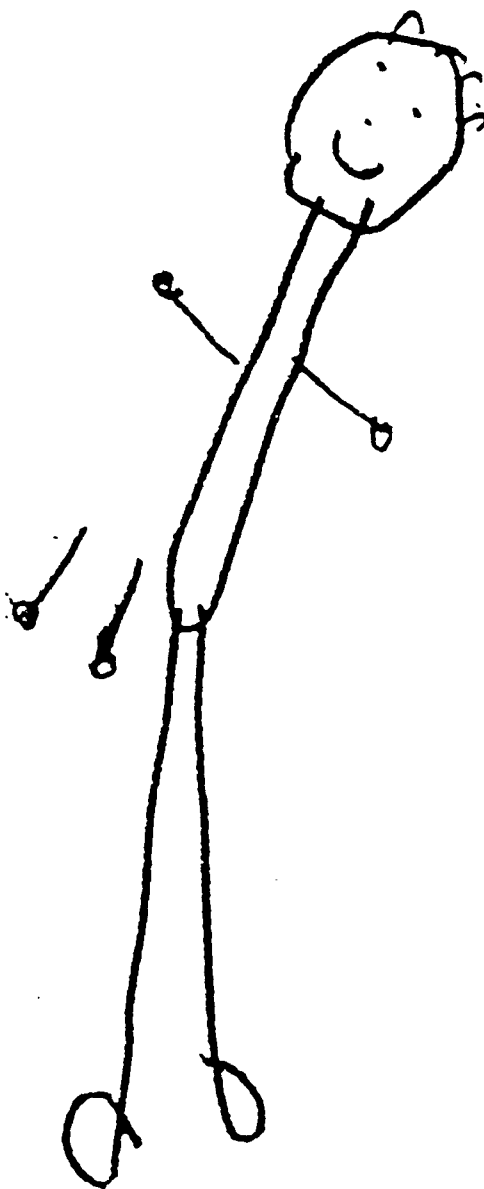
(b) shape change



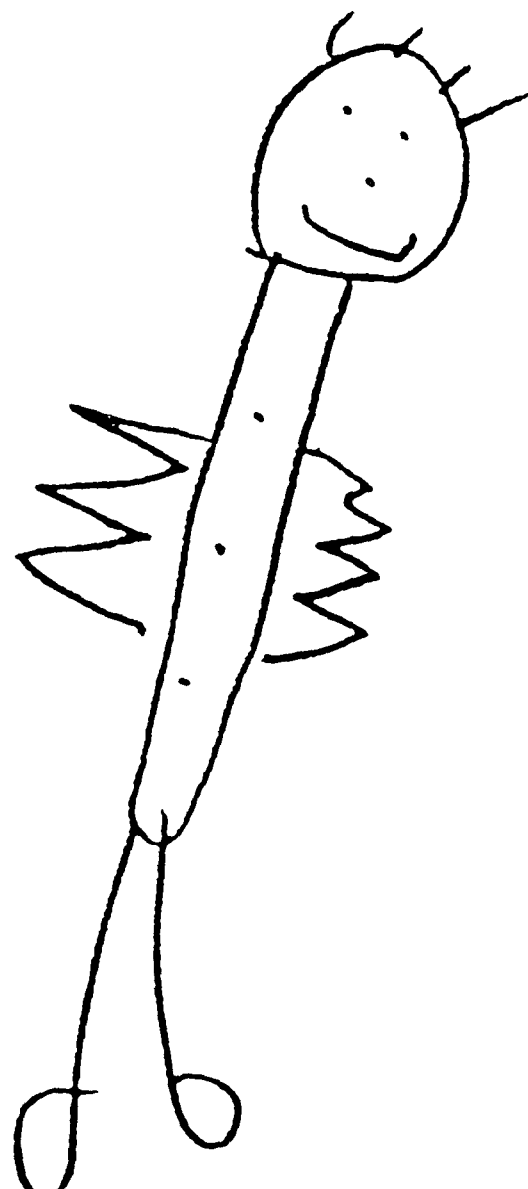
(c) deletion



(d) insertion (same category)



(e) re-location



(f) insertion (cross category)

Figure 9 Problems in drawing men which do not exist, Michelle 5 years 1 month.

first attempt began with wings which completely filled the page. On his second attempt he began with the head and drew the wings last. Neil (5:3), who normally began his drawings with the legs, had a problem drawing the example of a man with legs extending from his arm. He began by drawing the legs in the usual place, and when he came to draw the legs from the arm he realised that he had already drawn them "I done the legs there!" On his second successful attempt he started with the body and drew the legs last. These problems could again be explained in terms of a lack of planning.

#### **7. Experiment 4 - The effect of copying<sup>3</sup>**

Karmiloff-Smith has further claimed that 5-year-old children had difficulty even copying a drawing of a man with two heads. They succeeded only slowly and laboriously by, on her account, creating a new procedure rather than operating on an existing one. Copying in general is a slow and laborious task. This experiment sought to test the claim that copying a man with two heads would be more difficult (slower) than copying a comparable drawing which did not involve interrupting the normal drawing routine. In this case, a man with a hat and a bow tie - which on Karmiloff-Smith's account could be added to a finished drawing of a man. These extra elements controlled for the additional length of line involved in copying an extra head, making the two copying tasks comparable. The simple drawing of a man was included for comparison although it was anticipated that this would be completed faster than either of the copying tasks.

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<sup>3</sup> I would like to thank Prof. M. Boden for drawing my attention to the need to account for this aspect of Karmiloff-Smith's results.



7.1 Subjects

Ten children from Olney First school (Buckinghamshire), not used in previous studies, were tested individually. Their ages ranged from 5:3 to 5:10, mean age: 5:6.

7.2 Procedure

All the children were first asked to draw a picture of a man. Half the children were then given the picture of a man with two heads and asked to copy it followed by the picture of a man with a hat and bow tie. The others were presented with these tasks in reverse order. This procedure was videotaped and time taken to complete each drawing was extracted from the video-tapes.

7.3 Results and Discussion

simple	hat & tie	two heads
65.5	98.9	99.7

Figure 10. Mean time (in seconds) for simple drawing and copying tasks

An analysis of variance indicated a significant effect of task type:  $F_{(2,18)} = 5.953$ ,  $p < 0.01$ . A Scheffe F-test showed that there was no significant difference between the two copying tasks, but that both copying tasks took significantly longer than the simple man drawing task. These figures illustrate that copying is a long laborious process relative to normal drawing, but that this process is not different for tasks which do and do not involve "operating on procedures". Children will spend as

much time getting details such as the number of buttons right, as in noticing how the second head attaches.

## 8. Conclusions from the drawing task

Karmiloff-Smith (1986; 1990) provides a detailed model of representational redescription which was outlined in chapter 2 and will be analysed further in chapters 4 and 5. The model involves a basic underlying representation in terms of computational procedures and a mechanism for repeatedly redescribing these basic procedures first into more general and then into more accessible representations. The motivation for these redescriptions is stable successful performance. By employing the computational metaphor, Karmiloff-Smith has made very specific and testable claims, some of which, it has been shown in this chapter, cannot be supported.

In her drawing task Karmiloff-Smith sought evidence of the rigidity of a basic procedural representation in children's performance. It has been argued in this chapter that this type of rigid behaviour is not evident in children's drawing. Children do not produce the elements of a drawing of a man in strict sequence and they are easily able to make modifications to their productions in the middle of executing the drawing. Drawings are not produced by executing procedures or *a fortiori* compiled procedures. It has further been shown that Karmiloff-Smith's finding that younger children did not spontaneously produce certain type of modifications to their drawings, could be explained simply in terms of children's difficulties in understanding the requirements of the "draw a man that does not exist" task together with a lack of inventiveness. By giving explicit instructions it was found that young children *were* able to make all the types of modifications to their

drawings which, on Karmiloff-Smith's account, should have been possible only for older children with 'redescribed representations'. Considering the normal development of drawing skill, children *must* be able to make some modifications in the middle of their 'procedures'. For example, drawing a neck is a late development which could never be tacked on at the end of a pre-existing procedure.

The development of drawing skill seems to involve constant monitoring and adaptation of the production process, and it seems essential that the child should have access to that process. The children in our studies were not instructed to give protocols, but a few spontaneous comments were made (particularly by the youngest children) indicating that verbalisable 'metaprocesses' were involved. These comments indicated both advance planning e.g., "I'll have to draw the head bigger" (Leigh 5:7, anticipating problems with fitting in a beard), and on-going monitoring such as "that looks like his head" (Neil, 5:3, on having drawn a rather rounded body). These comments, often made during the execution of a drawing, are not consistent with Karmiloff-Smith's idea that 4-6 year old children do not have verbal access to, or awareness of the production process. On the contrary, there were indications that children were using language to control and monitor their productions (consistent with a Vygotskian account - Vygotsky 1978).

The drawing data addresses the issue of the representational format associated with Karmiloff-Smith's model, rather than the notion of representational redescription per se. It could be argued that drawing skills are not represented as *procedures*, but in some other format consistent with the representational redescription model. However, many of the characteristics of computational procedures are essential to

Karmiloff-Smith's model of the redescription process. Any candidate representation would need to be inaccessible - otherwise there would be no need for a redescription process, and it would need to produce consistent performance over repeated executions - otherwise there would be no motivation for the redescription process. Neither of these characteristics were found to be consistent with the observations of children's performance: a flexible, accessible production process was found. This argument is developed in chapter 5.

The problem of defining 'success' in the drawing domain was outlined (in section 6) and this concept is, at best, underspecified in the model. Children's drawing abilities obviously do continue developing beyond the achievement of an initial recognisable depiction. The lack of any recognisable point of 'behavioural success' means that it is impossible to apply the 'representational redescription' model, as it stands, to development in this domain. Indeed, from the child's perspective there may be a series of 'successes' on the way towards their final depiction formula. For example, when they manage to draw a clothed person, when they manage to draw hands with five fingers etc. This point, again, is elaborated in chapter 5.

The hypothesized mechanism for stimulating the redescription process, the concept of 'stable success' is another fundamental problem for the model. The 4-6 year old children at the focus of Karmiloff-Smith's account are still developing their drawing skills and their progress would seem to involve a continual series of minor modifications to successive productions rather than a stage of 'stable success'. Many of these changes are based on observations of more capable peers, for example "I'm going to do hands like Julie does". It may be that external factors have a more central role to play in

representational development 'beyond behavioural success' than Karmiloff-Smith's account allows. The role of the environment and the concept of 'stable success' will be discussed further in chapter 5.

Karmiloff-Smith has outlined a detailed model of Representational Redescription, which allows specific claims to be tested. Unfortunately, the domain of children's drawings does not provide the required support for the model. Karmiloff-Smith (1992, and personal communication, appendix 1) has accepted the points made in this chapter (Spensley 1990) and with hindsight believes that children's drawings is a particularly problematic domain. This is due to the external trace which drawings leave during production. This effectively cues the children as to where to restart<sup>4</sup>. However, she does not wish to drop the idea of sequential constraints in initial representations prior to representational redescription.

In chapter 5 the RR model is examined in detail in terms of its internal consistency. The concern, in this chapter, with the lack of behavioural evidence for the initial representational format, will be supplemented with an analysis of its theoretical plausibility as a part of the overall model. More experimental data will be examined in chapter 4, where the classic 'block balancing task' is re-examined. The drawing data will be reconsidered in chapter 9 when an alternative to the representational redescription account is proposed.

## **9. Towards a new a model of Representational Redescription**

Whilst rejecting the conclusion of Karmiloff-Smith's drawing studies, the difference in spontaneous changes to drawings with age was

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<sup>4</sup> Thanks also to Dr. S. Draper for making this point in a personal communication.

replicated. The conclusion that the younger children were 'less inventive' than the older children does not explain the processes behind the differing levels of inventiveness. Being inventive clearly involves cognitive flexibility, and thus the difference requires explanation. There are two possible explanations which will be proposed at this stage. The first is that the difference relates to processing capacity and secondly that children lack the ability to plan their drawings.

### **9.1 Creativity and capacity limitations**

The age-related sequence in types of transformations on drawings was replicated in this experiment. Younger children spontaneously changed the size or shape of a drawing part<sup>5</sup> or deleted parts of their drawing, but only the older children were able insert parts either from the same or different categories, or to change the orientation of constituent parts. There was nothing preventing the younger children from executing the alterations when they were specified for the children, i.e. the creative part had been removed, but then they would follow the instructions, but they did not appear able to generate their own variant.

The types of spontaneous creativity shown by younger children relate to individual parts of the drawing, and alterations to those parts. These changes could be made at a local level, with the specific part being the focus of attention either for change or for deletion. In contrast, the changes made by the older children involved an overview of the complete drawing (or at least more than one element of the drawing). Inserting an element from the same category requires reorganising the

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<sup>5</sup> The category of 'size or shape of the whole' was previously queried. In this context, it will again be subsumed under 'size and shape of part', although this category may involve more than one part.

normal pattern of relating between, for example, body and legs to insert an extra pair of legs. Changing the relationship between parts of the drawing requires attending to the relationship between those parts and holding both locations in mind at the same time. The last developing category, that of cross-category insertion requires relating the complete relationship between the part of the man drawing and comparing it with the relationship between the parts of a pig drawing, for example, and then generating the transfer of one element e.g. trotters, from its position in the pig drawing to the same relative position in the man drawing i.e. legs. It thus involves comparing relationships.

The differences here indicate that more information needs to be held in central processing for the creative process to operate. In the earliest modifications, only a single element of the drawing needs to be manipulated. In the most advanced modifications, the whole man drawing plus a representation from another category must be manipulated together. A possible explanation for these differences, will be elaborated in chapter 8.

## **9.2 Drawing and planning**

Making modifications to stereotyped drawings may be more amenable to an explanation based on planning. The children tested did have a few problems in executing certain modifications, and it is possible that these problems involved failures to plan. It is possible that Karmiloff-Smith was providing children with a planning problem rather than a drawing task *per se*. As all the children were able to draw a simple man the ability to 'operate on a drawing procedure' could be dependent on the development of an independent ability to plan. Alternatively, the lack of an ability to plan within the drawing task could reflect

inadequately redescribed knowledge, consistent in general terms with Karmiloff-Smith's account.

There are few references to planning in the literature on children's drawing and nothing which is more than descriptive. However, there is some evidence that young children, of the ages studied by Karmiloff-Smith, do spontaneously plan while executing their drawings. Thomas and Tsalmi (1988) have argued that children typically draw a person's head disproportionately large because they are planning for the inclusion of facial details, rather than because they have an anomalous conception of the human figure. Henderson and Thomas (1990) have supported this contention in a study of 4 to 7 year olds. They found that the relative proportions of the head and trunk were varied when children were asked to make different types of modifications to their drawings. Henderson and Thomas (1990) asked their subjects to draw a man and then asked them to draw either a man with teeth, a man wearing a jacket with buttons and pockets, a man viewed from the back (no face) or the twin brother of the first man. The twin brother condition produced similar head-trunk proportions in both drawings, the jacket condition produced significantly larger bodies, and the rear-view condition resulted in significantly smaller heads. The teeth condition did not produce a significant increase in head size, but Henderson and Thomas argued that as the head was already drawn over-large it may have reached a ceiling.

This study provides evidence that children do plan when executing drawings once they are capable of 'behavioural success'. It does not throw any light on the issue of how planning develops, or when it is applied to drawing tasks. It is generally accepted that children's early drawings are not planned - initially they name their drawings *after*



execution, rather than before. However, there are no studies on the transition from unplanned to pre-formulated drawings. This study provided anecdotal evidence that children have explicit knowledge of their own drawing abilities, and are able to anticipate what their efforts will produce. For example, a 4 year old girl who stated that she could not draw men, only girls because she could not draw short hair. This is evidence of anticipation of the likely outcome of the activity, but not actually of planning the activity.

Drawing is a difficult domain in which to study planning, because there will be problems in drawing *execution* due to a lack of drawing skill which will interact with planning problems, particularly for the younger subjects. A comment, such as "I've drawn his head too small" could indicate either a lack of planning or a problem with the motor execution. The problem of isolating production difficulties from problems of inadequate *planning* means that drawing does not provide an ideal domain for studying planning development in young children. The topic of planning development will be discussed further in chapter 6 and 7.

## 10. Summary

In chapter 1, it was argued that Karmiloff-Smith's (e.g. 1986, 1992) model of Representational Redescription provided the most promising approach to understanding cognitive flexibility. In this chapter one specific detail of the model was tested, the claim that initial successful representations are compiled procedures. In the drawing domain, at least, this aspect of the model was not supported as the children's productions were shown to be far more flexible, and accessible than predicted by the RR model. Two additional problems with the RR

theory were also discovered, namely the concepts of behavioural success, and of stability as the stimulus to redescription. These will both be discussed further in chapter 5. Karmiloff-Smith's (1990) observation of a difference in modification type with age was replicated, and planning and creativity development were suggested as potential explanation. These will be pursued in chapters 7 and 9 respectively. In the next chapter, consideration is given to the broader RR model, and a different knowledge domain, with a replication of Karmiloff-Smith's (1984) block balancing task.

## **Chapter 4**

### **Representational Redescription: evidence from a block balancing task**

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#### **Chapter Abstract**

The data from children's drawing presented in chapter 3 has cast doubt on the representational detail of Karmiloff-Smith's (1986) model. In this chapter a partial replication of Karmiloff-Smith's (1984) block balancing task is reported, which should produce evidence of all three phases of the RR theory. The theory predicts different block balancing behaviours in each of the three phases, and an additional quantitative prediction in terms of 'time to balance' the blocks was made. There was evidence of a rigidity in performance with some 'phase 2' subjects, but overall there was a broader range of performances than predicted by Karmiloff-Smith (1984). The times taken to balance the blocks showed that subjects of all ages had a preference for central placement, The RR model Case studies indicated that success, even in this clearly defined domain was not an unitary state.

#### **1. Introduction**

his chapter will report an analysis and partial replication of Karmiloff-Smith's enduring block balancing task (Karmiloff-Smith and Inhelder 1974, Karmiloff-Smith 1984; 1986; 1987; 1992). Karmiloff-Smith

and Inhelder's (1974) block balancing experiment provides the earliest data which Karmiloff-Smith has related to her RR theory. The original paper pre-dates the RR theory, but Karmiloff-Smith has referred back to this paper frequently to illustrate her RR model (e.g. Karmiloff-Smith 1984; 1986; 1987; 1992). The example was also quoted earlier in chapter 2 when describing the RR theory.

### **1.1 Karmiloff-Smith's Block Balancing Task**

Block balancing should provide a clear illustration of the RR theory, because the distinction between failure and 'behavioural success' is absolute: a block either balances or it doesn't. In addition, it is claimed to produce a spontaneous 'u-shaped' behavioural curve which provides behavioural evidence of the proposed underlying representational change. The block balancing task is quite unlike the drawing task (discussed in chapter 3) in both of these respects.

Karmiloff-Smith (1984) provides a clear-cut description of her block balancing task which is a slight simplification of the task described in the original paper (Karmiloff-Smith and Inhelder 1974). It was this simplified version of the task which was quoted in chapter 2. Karmiloff-Smith (1984) has also simplified the developmental progression outlined in Karmiloff-Smith and Inhelder (1974). She describes the children's behaviour as fitting clearly into the three distinct levels of the RR theory, which is (presumably) a re-analysis of the original observations which were durably recorded in written and audio-taped form. However, there are no quantitative data from the re-analysis which would allow an evaluation of the new interpretation to be made. The original paper was written in a discursive 'Genevan' style, and so did not contain any quantitative data either, it was an interpretation of detailed observations. Whilst such an approach may

provide useful insights, the only way to evaluate such accounts is to replicate the findings and a partial replication of the study will be reported in this chapter. Karmiloff-Smith's 1984 'redescription' of the 1974 experiment extracts the elements of the study which clearly fit the RR theory. As the focus here is on the RR theory, the replication design will focus on this later account. However the experimental details have been taken from the 1974 paper (in so far as they were provided).

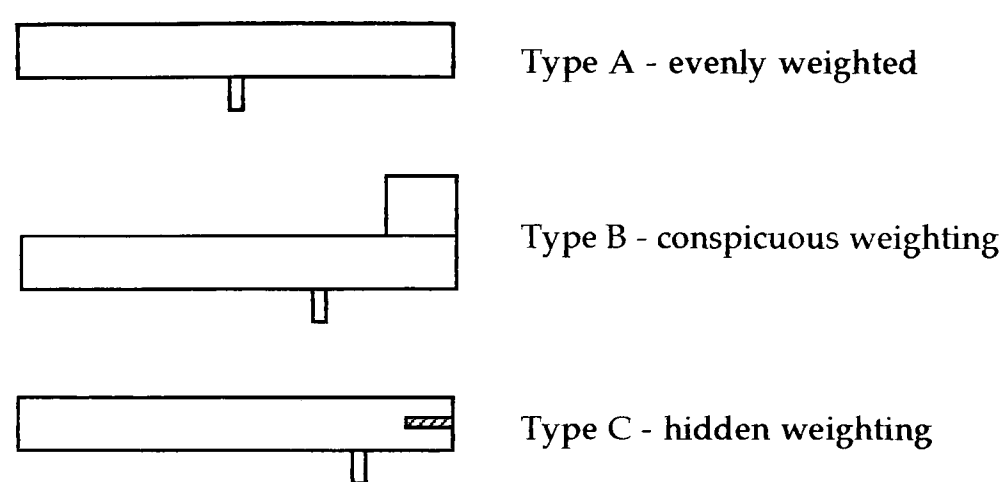


Figure 11. Examples of blocks with their points of balance.

Karmiloff-Smith and Inhelder's (1974) original study involved 4:6- to 9:5- year-old children who were presented with a selection of wooden blocks to balance across a narrow metal bar (1 cm wide) fixed to a block of wood. There were three main types of block with several variants within each type. The three categories of block were: Type A blocks which had their weight evenly distributed so that their centre of gravity corresponded with their geometric centre; Type B blocks which were conspicuously-weighted at one end; and Type C blocks which were inconspicuously-weighted at one end with a metal implant (see figure 11). The extent of the weighting, and thus the point of balance, varied between exemplars for both categories of weighted block. Children were presented with the complete selection of blocks and could select them in whichever order they wished. The order in which blocks were selected

was noted, as were the types of blocks which the children were able to balance successfully.

Karmiloff-Smith (1984, describing Karmiloff-Smith and Inhelder 1974) found three levels of 'successful' balancing performance. The youngest subjects studied (phase 1) were entirely successful. They simply moved each block backwards and forwards across the bar, until through proprioceptive feedback processes, they achieved a balanced position for the block. Each block was treated as an isolated problem, and the blocks were selected randomly. In terms of the RR theory, they had an inaccessible balancing procedure.

Phase 2 children were only able to balance the type-A blocks. That is, those blocks whose centre of balance corresponded with their geometric centre. They did not engage in the adaptive manipulations of the younger children, they repeatedly placed each block with its geometric centre on the bar. When the type B and C blocks repeatedly failed to balance, they labelled them as "impossible to balance". Even if the experimenter placed and left an identical block in balance on the bar, they still attempted to balance their block in the centre.

Karmiloff-Smith (1984) argues that this consistent approach to the problem was due to the phase 2 children using a 'single unified procedure' for balancing. There was no problem with the children's proprioceptive feedback processes, as they reverted to using them if they were asked to carry out the task with their eyes closed (they then succeeded on the task).

At phase 3 the children began by placing the blocks on the bar at their geometric centres, but quickly adapted the balancing position (using proprioceptive feedback) when the bar fell. Their success differed from

phase 1 subjects in that they began by trying the geometric centre of each block (indicating a geometric centre 'theory in action'). They also displayed a unified approach to the whole experimental task, rather than treating each block in isolation. Having successfully balanced a block of a particular type, they then selected a similar block and used the information gained from their previous success to assess the point of balance of the new block. They did not try the geometric centre first for the subsequent blocks.

## **1.2 Siegler's block balancing task**

Karmiloff-Smith is not the only person to study the development of balancing skill, nor the only one to discover a U-shaped performance in balancing. Siegler (e.g. Richards and Siegler 1982) has used a balance scale task, which is, of course, a different problem than that studied by Karmiloff-Smith. In many ways it is an easier task, as the relevant variables are more obvious than the hidden weights used in the Karmiloff-Smith variant. Siegler's problem involved the prediction of the behaviour of a balance scale where the number of weights and the distance from the fulcrum could both be varied. His explanation of the u-shaped behaviour was in terms of the interaction of the specific problems with the underlying rules. Only certain problems with conflicts of weight and distance would produce a u-shaped behavioural curve. He demonstrated how a constant development in terms of rules could therefore produce a u-shaped behavioural curve in performance (on a particular problem set).

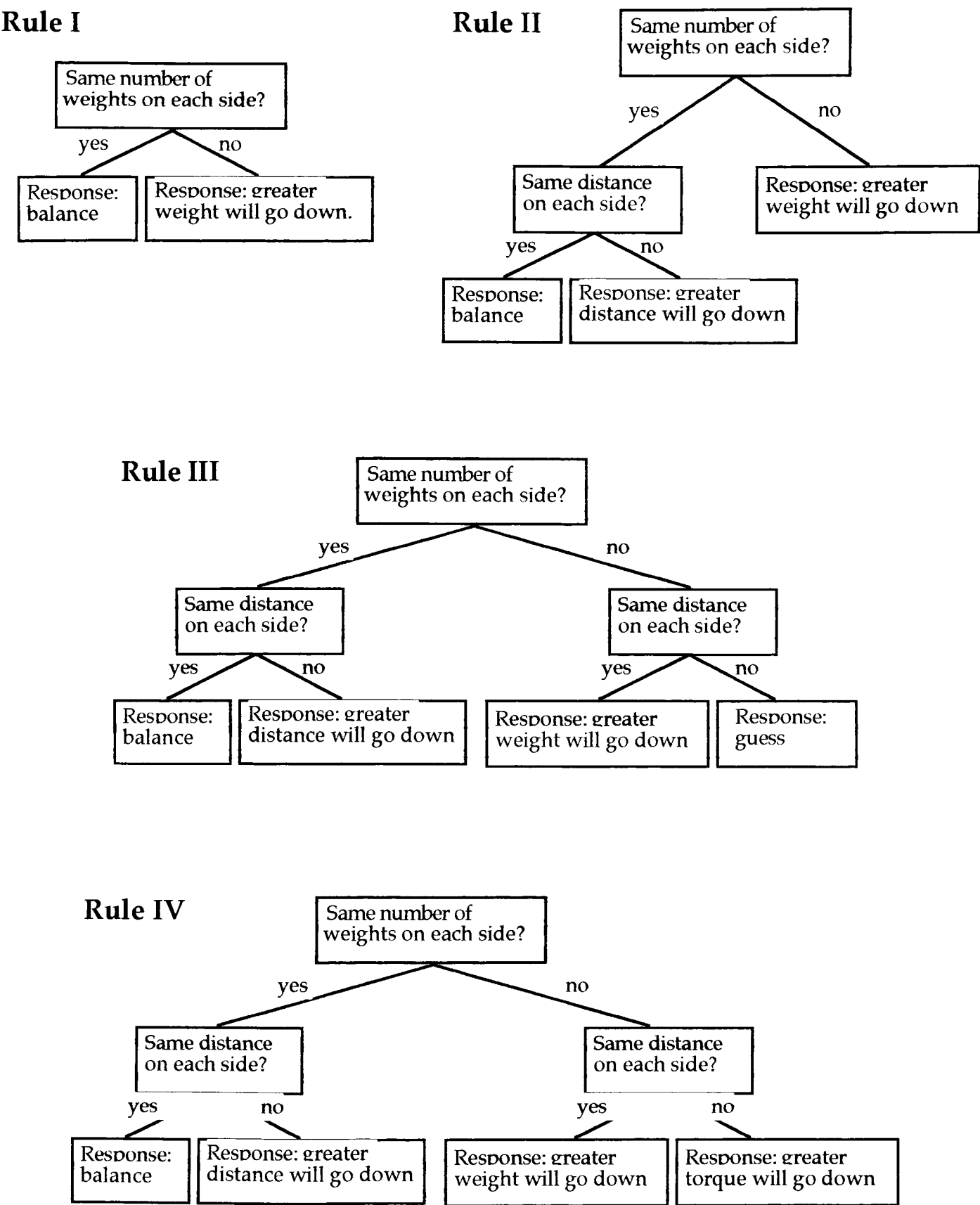


Figure 12. Increasing balance rule sets, from Richards and Siegler (1982)

The balance scale problems used by Siegler are of a type encountered by children in their school work. They would therefore be more familiar with the task than Karmiloff-Smith's subjects. Siegler also required a verbal prediction, basically a forced choice of three clearly defined



responses (tip left, tip right, balance). The response required from the Karmiloff-Smith task is far more open ended, the subjects are required to achieve a state of balance, by ill-defined means. There is no scope for guessing!

The problems in the two experiments are different, however, success will requires a similar amount of knowledge: how to compensate for weight and distance differences. However, the relevant factors weight and distance are highlighted in Siegler's experiment in the equipment. Karmiloff-Smith's task requires children to identify the relevant dimensions. Siegler's rule acquisition approach provides a useful, formal, account of similar behaviour, with which to compare performance on Karmiloff-Smith's task. Block balancing could be explained as gradual rule development, isolating the relevant factors, initially weight and then distance (in Siegler's task), and then understanding how these factors interact to affect balancing.

### **1.3 Experimental hypotheses**

The present experiment is concerned with analysing the RR model. Karmiloff-Smith's (1984) description of three phases quoted above, provide a clear hypothesis in terms of phase-related success at the balancing task. Phase 1 children should balance all the blocks, phase 2 children (around 6 years old) dominated by an overwhelming top-down theory, should fail to balance any but the type A (evenly-weighted) blocks. If persuaded to persist they should spend a long time failing to balance all of the other blocks. Phase 3 children should, like phase 1 children, balance all the blocks. The relative time taken to balance the different blocks should vary between phase 1 and phase 3 children (absolute times will clearly differ according to manual dexterity). Phase 3 children who start in the centre, should balance type A blocks more

quickly than the other blocks, and the time taken to balance should be proportional to the distance from the centre of the point of balance. Phase 1 children, on the other hand should take equal amounts of time to balance all of the blocks as, according to the theory, they should just place the block at a random point and then use proprioceptive feedback to achieve a balance.

A pilot study of 8-year-old children, were presented with the complete selection of 12 blocks, as 'block selection' was to be a dependent variable. However, these children (who were expected to select blocks systematically) simply chose the block nearest to them on the table. This may have been due to the layout of the blocks, the limited space in the experimental room or the fact that the children were seated at a table. However, a lack of information on the layout used by Karmiloff-Smith and Inhelder (1974) meant that this feature of the original experimental design was not pursued with younger subjects.

The experiment reported here was flawed by changes in the procedure between age groups (as the experiment progressed). The quantitative data must, therefore, be treated with caution. However, enough useful data and qualitative observations were collected to justify reporting the work. Identified weakness in design and procedure will be reported in footnotes<sup>1</sup>. The primary aim was to replicate Karmiloff-Smith's findings as the basis for pursuing the RR model and to collect some quantitative data to test the model. The secondary aim was to analyse the performance of subjects to check the accuracy of the 1984 re-interpretation of the original 1974 observational data.

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<sup>1</sup> The first weakness being that the experiment should have been re-run!

## 2. Method

### 2.1 Subjects

30 children were tested, covering the age range 4:3 to 8:3. The youngest five subjects were tested at Bozeat<sup>2</sup> Community playgroup (mean age = 4:5, hereafter referred to as '4-year olds'), the others were drawn from the first four classes at Bozeat primary school. Class 1 (n = 8, mean age = 5:2); class 2 (n = 8, mean age = 6:2); class 3 (n = 5, mean age = 7:1; class 4 (n = 4, mean age = 8:1). Hereafter referred to as 5-, 6-, 7- and 8-year-olds, respectively. Subjects were tested individually in a private room.

### 2.2 Materials

Three sets of hollow cardboard blocks were used: large and small blocks both with a rectangular cross section, and triangular with an equilateral triangle cross-section. The proportions of the blocks were as follows: small - 17.2 cms x 2.8 cm x 3.5 cm; large - 29 cms x 3.7 cm x 4.2 cm; triangular - 20.8 cms x 3.6 cm equilateral triangle cross-section. For each shape of block there were four weighting-types: evenly-weighted, conspicuously-weighted, and two types of inconspicuously-weighted blocks slightly-weighted and very-weighted<sup>3</sup>.

As a measure of how 'off-centre' the blocks centre of balance was, an index was calculated for each block as follows:

$$\frac{\text{distance of balance point from centre}}{\text{length of block}} \times 100$$

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<sup>2</sup> Bozeat is village in Northamptonshire, with a mixed population varying from manual workers to professionals in an area of low un employment.

<sup>3</sup> The weightings were largely random within these categories. It would have been better to have been systematic in the degree off-centre of the centre of balance.

This expresses the point of balance as a percentage of the distance between the centre and the end of the block. These measurements are summarise in table 1.

	evenly weighted	slightly weighted	conspicuously weighted	very weighted
small	0%	22%	42%	49%
large	0%	18%	27%	41%
triangular	0%	12%	33%	47%
average	0%	17%	34%	46%

Table 1. Relative point of balance for each block type.

The blocks were balanced on a wooden bar 0.8 cm wide (1.9 cm wide for 4 year-old subjects)<sup>4</sup> and 30 cm long, on a wooden base.

### 2.3 Procedure

All children were pre-tested by asking them to balance an evenly-weighted block (208 x 27 x 18 mms) across the bar, to check manual dexterity. The pre-test block had a different appearance from the experimental blocks. 4-year-old subjects who were not able to pass this pre-test were then given the broader bar. All then succeeded. Two 5-year-old subjects were dropped from the experiment after failing the pre-test, due to a complete lack of interest and perseverance with the task.

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<sup>4</sup> Ideally this should have been 1 cm wide for all groups, as in Karmiloff-Smith' & Inhelder's study.

Five-, 6- and 7-year old subjects were presented with the set of four small blocks, to balance in any order they wished. They were only presented with one set of blocks, due to the time taken by some children to achieve a balance (or to give up). Children were free to balance the blocks in any order<sup>5</sup>, and to change blocks whenever they wished. All the children were encouraged to persevere with balancing the problematic blocks. If they were losing patience children were encouraged to try a different block and the experimenter demonstrated that the problematic block *could* be balanced. As each block was successfully balanced it was removed by the experimenter to a 'completed' group, still visible to subjects. Unsuccessfully balanced blocks were returned to the subject's block pool for a subsequent balancing attempt. The session ended with the successful balancing of all the blocks, or with the subject 'giving up'.

The 4-year old and 8-year-old subjects were tested after the 5- to 7-year olds, and they received a more formal presentation<sup>6</sup>, to allow for more accurate timings. These children were presented with each of the twelve blocks individually and asked to balance them across the bar. Subjects were allowed 4 minutes to balance each block, after which the trial was terminated. The time limit was imposed to encourage subjects to persevere when they encountered initial difficulties whilst ensuring that subjects who could not achieve a balance did not become bored with the task before all the trials were completed. After each trial the block was removed from sight. Blocks from each set were presented in sequence in a counterbalanced order (e.g. all the small blocks, then all the triangular blocks, then all the large blocks). The order of

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<sup>5</sup> This introduced an order effect, in that children tended to avoid the conspicuously weighted block, and it was tried last by 11 of the 19 children. Only 2 of the children selected it first.

<sup>6</sup> With hindsight, this design should have been used for all subjects.

presentation within these sets (e.g. conspicuously-weighted, very-weighted, evenly-weighted, slightly-weighted) was also counterbalanced.

All subjects were video-taped and the time taken to balance each block extracted from the tape after the experimental session. Timings were recorded to the nearest second<sup>7</sup> and they were measured from the point at which a subject's hand first touched a block until her hand left the block either on achieving a balance, or when replacing the block on the table. Where more than one attempt was made with a specific block the times for each attempt were totalled<sup>8</sup>.

### 3. Results

Due to the different experimental procedures, data on all twelve blocks are available for the 4-year-old and 8-year-old subjects, and data for the small block set only are available for the 4-, 5-, 6-, and 7-year olds. One 5-year old child, having passed the pre-test, failed to balance any of the experimental blocks. This was due to a lack perseverance with the task, and his session will not be included in any of the analyses.

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<sup>7</sup> Timings to any smaller units would provide a spurious impression of accuracy. However, differences were large enough for units of a second to discriminate easily between conditions.

<sup>8</sup> The timings are only a rough indication of problem difficulty, due to this summation process. However, the differences in times between blocks were large enough to be worth reporting. The timings for the playgroup subjects and the 8-year old subjects are more precise as they relate to a single balancing attempt.

	evenly weighted	slightly weighted	conspicuously weighted	very weighted
4 year olds	100%	100%	60%	20%
5 year olds	83%	33%	17%	0%
6 year olds	100%	100%	75%	63%
7 year olds	100%	100%	80%	80%
8 year olds	100%	100%	100%	100%

Table 2. Percentage of children balancing blocks successfully: small blocks.

	evenly weighted	slightly weighted	conspicuously weighted	very weighted
4 year olds	93%	80%	60%	27%
8 year olds	100%	100%	100%	100%

Table 3. Percentage of children balancing blocks successfully: all 12 blocks.

The general pattern of results, in terms of balancing success, indicates a drop in performance at the 5-year old level, consistent with Karmiloff-Smith and Inhelder's (1974) observations (see table 2). None of the 5-year-olds could balance the very-weighted block, and only 33% could even balance the slightly-weighted bar. This result is slightly confounded with the use of the wider bar by younger subjects which might have led to improved performance, particularly on the slightly-weighted block. Another confounding factor was a clear difference in effort between the 4- and 5-year olds, reflected in the fact that, in total, three subjects had to be dropped from the experiment for not persevering with the task, and they were all 5-year-olds. However, there were clear behavioural differences with evidence of an overt

'centre-fixation' in the 5-year-old children, which provides a counter to these confounds. This evidence will be discussed further in section 4.

As Karmiloff-Smith's (1986) representational phases are not age-related, it was more important to categorise subjects by their performance than by their age. It was straightforward to categorise the children in this study into 4 performance levels according to the number of small blocks they could balance. There was a clear sequence in terms of which of the four blocks could be balanced. If children managed to balance only one block, it was the evenly-weighted block (performance level 1). If they balanced two, it was the slightly-weighted block (22% off-centre) as well as the evenly-weighted one (performance level 2) . If they could balance three, they only failed to balance the highly-weighted (49% off-centre) block (performance level 3). Performance level 4 was successful balancing of all the blocks. The distribution of children into the 4 levels by age can be seen in figure 13.

Percentage of children

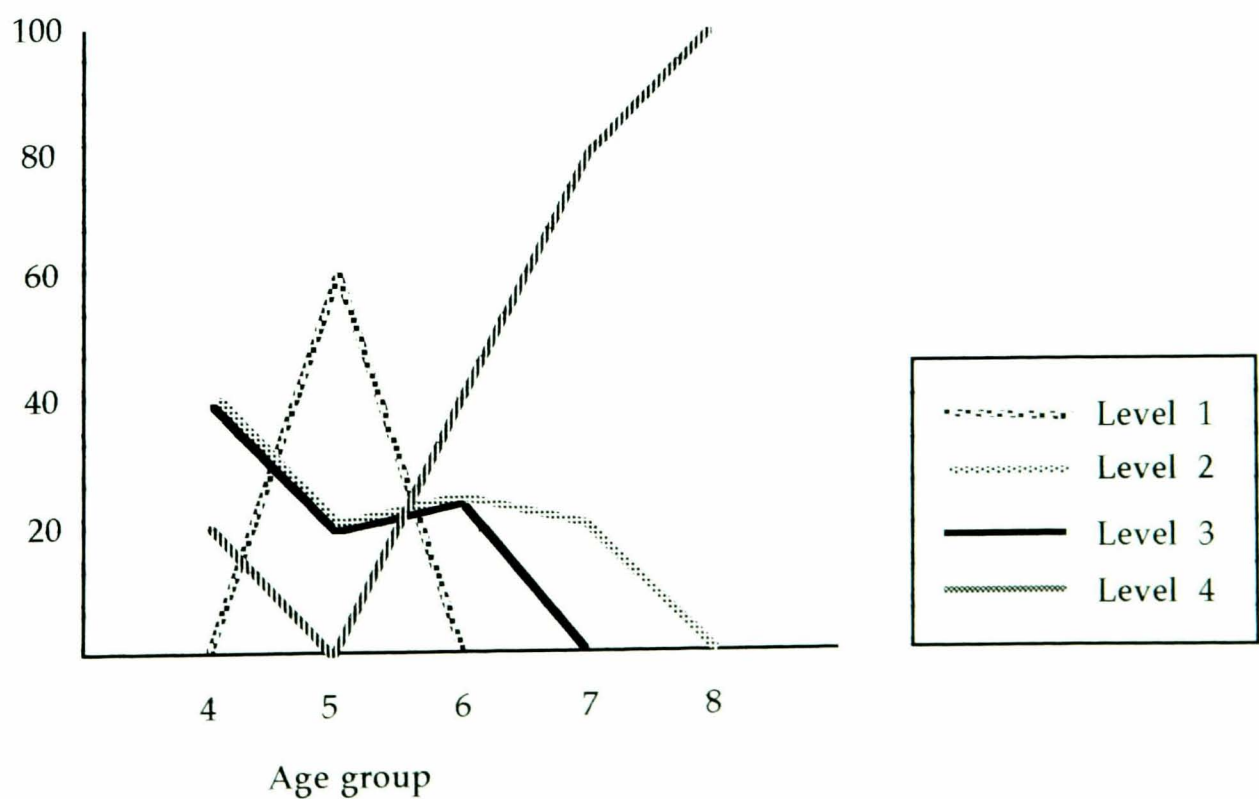


Figure 13. Percentage of children at each balancing level, by age group.



The absolute time taken to achieve a balance was found to vary between individuals, more than between performance levels or age groups. The time taken to balance the evenly-weighted block could be taken as a baseline of manual dexterity, and there was no correlation of this timing either with age ( $r = 0.009$ , n.s.) or with performance level ( $r_s = -0.143$ , n.s.).

Times to balance each of the off-centre blocks were converted to ratios of the baseline time for the relevant individual. This procedure eliminated the problems of individual differences and allowed performances to be compared. The relative time taken to balance the blocks, within each performance level, reflected the degree off-centre of the balance point: it took subjects of all performance levels significantly longer to balance a block if its point of balance was further from the centre. (Level 2: Wilcoxon signed ranks,  $W = 2$  ( $p < 0.05$ ), Level 3 Friedman  $\chi^2$  (2 d.f.) = 10 ( $p < 0.0055$ ), Level 4: Pages L test ( $L = 360$ ,  $p < 0.001$ ).

The time to achieve a balance is most important in relation to the 4-year old sample, as our hypothesis (following the RR model), predicts equal times to balance all types of block. However, this age group showed the same progressions as the older children both in terms of which blocks were balanced, and in the time taken to balance them. They were more likely to balance a block the nearer its centre of gravity was to the middle, and they took longer to balance a more off-centred block.

## 4. Discussion

### 4.1 Support for Karmiloff-Smith's (1984) Model

In terms of quantitative results the predicted support for Karmiloff-Smith's model was not found. RR theory would predict that the youngest subjects would not show a 'centre preference' and would therefore take the same time to balance all the blocks. However, the same relative pattern of timings were found for all subjects: evenly-weighted blocks were balanced more quickly than slightly-weighted blocks, which in turn were balanced faster than the more-weighted blocks.

There was little evidence of the simple, procedural success attributed to children with 'phase 1' representations. The youngest subjects were more likely to be at the intermediate performance levels 2 or 3, than at the entirely successful level 4. Only 20% of the 4-year olds showed the 'level 4' balancing performance. The remaining 80% all had a problem with the very-weighted block. Further, the behaviour of *all* the 4-year-old children indicated a preference for a centred placement of the block. There was no evidence of the hypothesized simple proprioceptive feedback procedure.

RR theory predicts a simple division into two behavioural categories on the balancing task: those children who could balance all the blocks, and those who could balance only the evenly-weighted blocks. This was not found. There were a large number of children at the intermediate stages, performance levels 2 and 3. There is no place for these children in Karmiloff-Smith's 1984 theory. Joiner et al (in preparation) similarly failed to find evidence of the distinct behavioural phases, and argue for

a smooth developmental progression on the balance task. Although their study only tests the obviously weighted blocks. The behaviours associated with these intermediate levels will be discussed later in the chapter, in relation to individual case studies.

There was some evidence of the behaviours characterised by Karmiloff-Smith (1984) as indicative of 'phase 2' representations. These were found in the 4:11 to 5:9 age group (slightly younger than Karmiloff-Smith's 'phase 2' subjects who were 6-year-olds). The graph in figure 13 clearly shows the occurrence of 'level 1' behaviour only in the 5-year old age group. This is consistent with Karmiloff-Smith's findings, that a rigidity about placement at the centre of the block leads to a performance decrement in older subjects - a u-shaped behaviour. The 5-year-olds were indeed less successful (overall) at balancing than the 4-year-olds.

The 'level 1/phase 2' rigidity was not universally found in the five-year-old-group, and thus related to a small proportion of the total subjects. Karmiloff-Smith has proposed that the 'centre-theory' is a *necessary* stage in development. As this was not a longitudinal study, it is impossible to either confirm or deny this claim. However, the small proportion of subjects found to exhibit this behaviour must licence the hypothesis (for future studies) that 'level 1' performance may be a stage that only *some* children progress through.

Whilst replicating (between subjects) the interesting performance decrement which Karmiloff-Smith reported, the complete data set does not fit with her 1984 explanation. There *is* evidence of a rigidity in behaviour with the 'phase 2' children, but this does not appear to be due to a redescription of a simple phase 1 'proprioceptive feedback' procedure, as there is little evidence of such procedures (see Kelly's case

study below). The performance of the youngest children is guided by more than simply proprioceptive feedback, they do have some, perhaps implicit, 'notion' that things balance in the middle. They all started with a centred placement and there was evidence of a 'pull' towards the centre in making adjustments: those towards the centre were often excessive. However, they were clearly not dominated by the 'centre theory' in the way that the level 1 children were.

A further issue, which will be elaborated below is whether the representation underlying 'level 1/phase 2' performance should merit being described as a *theory*.

#### **4.2 Re-examination of the Karmiloff-Smith and Inhelder (1974) approach**

The RR model describes a limited range of children's behaviours on the block balancing task. The categorisation of children's behaviour into 4 performance levels in the previous analysis also oversimplifies their performance. In particular, both approaches provide a static measure of performance, when there were some apparent developments within the session. Examination of the video recordings indicated micro-genetic development in certain subjects during the experiment, and the final success or failure on the task was less revealing than the behaviour which accompanied it. Similarly, Karmiloff-Smith's (1984) description seems to oversimplify the range of performances which were originally observed.

The earlier paper (Karmiloff-Smith and Inhelder 1974) provides a more detailed account of the range of behaviours observed including a series of *seven* different action sequences (in contrast to the three described by Karmiloff-Smith 1984). Movement to a more advanced

action sequence was observed within sessions, and the sequences were presented as forming a developmental sequence. Whilst the observations from this study do not directly replicate the 1974 sequences, there are many similarities. These will be referred to later in the chapter, as case studies are reported. Karmiloff-Smith & Inhelder's (1974) developmental sequence is summarised in appendix 2.

The general approach of the earlier paper also highlights useful issues for analysing the present observational data. The focus of the original paper was

"... not on success or failure per se but on the interplay between action sequences and children's 'theories-in-action', i.e. the implicit ideas or changing modes of representation underlying the sequences."

Karmiloff-Smith and Inhelder 1974 (p. 196)

In particular they hypothesized that

"... children interpret the results of their actions on the blocks in two very different ways: either in terms of success or failure to balance the blocks which will be referred to as positive or negative *action response*, or in terms of confirmation or refutation of a theory-in action, which will be called positive or negative *theory-response*."

Karmiloff-Smith and Inhelder 1974 (p. 198, italics in original)

This distinction between the result of a balancing action and the *interpretation* of that result seems to be a crucial one. However, the limitation of the interpretation of the result to two possibilities: either simply as goal-achievement, or as evidence for a theory seems rather limited and presupposes the acceptance of the notion of the development of a *theory* as central to representational change. It may be useful to broaden the distinction.

Simon (1978) in his theory of problem solving, has characterised the problem solving process as an interaction between the problem solver and the task. The knowledge state of the individual determines how she encodes and represents the problem, it is this *representation* of the problem which then determines her next action on the problem. The result of the action may again cause an updating of the knowledge state, and of subsequent problem representations. Simon is talking about progressing through the stages of a complex problem, however, the insight can easily be applied to the repetition of attempts with a simple problem.

Rather than the simple presence or absence of a 'centre theory', consideration could be given to the underlying knowledge state in more general terms. Performance could be thought of as a cyclical sequence of acting, perceiving the result of the action, updating the representation, and acting again. The general circularity of action and representation is not a smooth process in the development of a concept of balancing. If a certain action, e.g. centre placement is repeated regardless of the failure of the attempt, then the representation is resistant to updating. The nature of this resistance requires explanation.

The child's knowledge state will affect how the subsequent attempt is made. In addition the encoding of the results of an action will affect the child's existing knowledge state (which again, in a recursive fashion) then affects her subsequent actions. These interactions will be discussed in terms of individual performances in the various age groups and balancing levels. In the following section we will analyse case studies and look at evidence of the 'interplay' between actions, representations, and encoding.

## 5. Observational data

### 5.1 Four-year-olds and procedural representations

As was mentioned in section 4.1 above, there is very little evidence of simple proprioceptive feedback procedures in the youngest subjects. The 'central tendency' observed in the youngest subjects in this study was also reported by Karmiloff-Smith and Inhelder (1974). They described it as an action sequence developmentally in advance of the initial random placement, but preceding the onset of the rigid 'central theory'. The 'central tendency' was due, they claimed, to a general interest in 'symmetry' in this age group. It is possible that the children tested in this study were all at this more advanced level, although they were the same age as those tested by Karmiloff-Smith and Inhelder (1974). This would be consistent with the finding of 'level 1' behaviour in 5-year-olds in this study whereas Karmiloff-Smith and Inhelder placed it at around age 6.

The occurrence of a 'central tendency' *before* phase 2 was not mentioned by Karmiloff-Smith in her later accounts (1984, 1986, 1993), although it does not necessarily refute the theory. An incidental 'central tendency' which is *implicit* in young children's balancing behaviour, (due perhaps to a general inclination towards symmetry), is quite different from an *explicit* belief that "things balance in the middle", which dominates performance. As such, this different type of behaviour could still be compatible with phase 1 of Karmiloff-Smith's RR model. However, the notion of an inflexible procedure as the basis for the behaviour of the youngest subjects is still questionable. Two case studies of 4-year olds will be described in an attempt to analyse the knowledge state of the younger subjects.

### 5.1.1 Remeo 4:3.

The youngest subject Remeo (4:3) performed at level 2 on the large and triangular blocks, and progressed to level 3 on the small blocks. He persevered, despite obvious boredom, with all the blocks until the experimenter terminated a trial. With the first set of blocks he showed a variety of behaviours, but with the later sets he rapidly got bored and quickly fell into a repetitive behavioural rhythm.

He was initially given the triangular block set, starting with the evenly-weighted block. This he placed immediately in a balanced position on the bar. He was then given the slightly-weighted block which he first placed in a centred position on the bar. On his second attempt he picked up the block with two hands and put it directly in a balanced position. He did not make any adjustments to the position, but placed the block deliberately and then let go with both hands at once. This might have been just a fortuitous placement, but he was also able to place the slightly-weighted large block immediately into a balanced position. If he was 'intuitively' using proprioceptive information, it was gained whilst lifting the block, as there was no adjustment made when it was on the bar.

The next block was the obviously-weighted block, which he centred on the bar (twice) and was amused when it fell. He then placed it off-centre but adjusted it to a centred position. He let go, but prevented it falling completely, and examined the face of the block which had touched the bar (hereafter referred to as the 'base'). He then replaced the block in a centred position and let it fall. On the next couple of trials he again looked at the base of the block as he was placing it, as if this held the clue to his failure. He did shift his placements slightly off-centre (once in the wrong direction), but never sufficiently either to



achieve a balance or for the block to fall towards the unweighted end. He later reverted to a centred position, and repeated his examination of the base of the block.

The very-weighted block was initially centred on the bar and, after it fell, Remee examined the base of the block. At one stage he gave the block a slight shake as he lifted it, but did not pursue this examination, and subsequently placed the block off-centre in the *wrong* direction for a few attempts. On one attempt he tried pushing down both ends of the block - perhaps trying to stick it to the bar? His usual behaviour was to use two hands and make a definite placement, hold it in position and then let go. But with this block he also tried a one handed technique, just lifting the weighted end, and then letting go. He was clearly able to use manual pressure to exactly counteract the weight and thus hold the bar in a balanced position, but had not extracted the relevant information from the *need* to counteract the weight, and *a fortiori* the implication of this for the position of the block on the bar. He rotated the block to place a different face next to the bar, and again looked at the base of the block. With obvious boredom, he established a minimum effort rhythm of sliding the block from its fallen position, towards a (roughly) centred one letting it go which was followed by a 'bang' as the weighted end hit the table. If the block was placed off-centre it was in the wrong direction, influenced only by how the block had fallen and Remee making an insufficient movement back towards the centre. His interest was caught by one fall which resulted in the block standing on its end, but he failed to repeat this on the subsequent alert attempt and returned to his repetitive placement rhythm. That is, he tried but could not extract any meaning from observing this result.

After this set of four blocks, the two blocks which Remee had failed

to balance were demonstrated, and this seemed to be both amusing and surprising. However, it had no effect on his subsequent performance.

His performance with the large blocks mirrored that with the triangular blocks. He balanced the even and slightly-weighted blocks immediately and failed, after persisting, to balance the very-weighted and obviously-weighted blocks. His performance with the very-weighted block involved centring the block, or placing it off-centre generally in the wrong direction (again through boredom, rather than through a positive placement decision). He once looked at the base of the block, but quickly fell into another unthinking behavioural rhythm, with little attention paid to block placement. Where blocks were deliberately placed they were centred, apart from one early trial where (for no apparent reason) it was put extremely off-centre in the wrong direction

The final set was the small blocks, and Remee started with the obviously-weighted block. He quickly 'gave up' and settled into a repetitive pattern of 'put the block on, let go, clunk, clunk (as it hit the table, and turned over); put on let go, clunk, clunk'. His attention was drawn when one 'clunk' was slightly softer and, he seemed to realise that this difference was significant. He picked up the block more slowly and placed it too far towards the weighted end (he had never done this before) and the block fell down on the unweighted side. He then placed the block in balance.

Remee had successfully executed a local solution, and balanced a type of block he had previously failed on. However, he had not extracted any general information from the experience. The following block was the very-weighted block which he then failed to balance, treating it just as he had done previously. He then balanced the even

block immediately. He was finally confronted with the slightly-weighted block, which he did not balance immediately. He quickly established a rhythm again of placing, letting go, and the block falling. When a casual placement did result in a balance, it took him almost by surprise. He had not consciously done anything different to make it balance.

Remee knew what the goal state was, because he could recognise success. However, he had no insight into the means to achieve that success. He did not seem to use proprioceptive feedback at all although he had the basis in his ability to counteract the weight, and therefore had some implicit knowledge about the balancing 'system'. Each block was considered in isolation, he could not verbalise anything about balancing. He had not done any activity specifically labelled balancing either at playgroup or at home. Remee seemed to think that balancing has something to do with the contact between the two surfaces, but he also had a definite tendency to balance things in the centre, although this was easily dropped, if some other position suggested itself.

Remee's representation of the problem did not lend itself to predicting the behaviour of the block. He did not analyse the features of the blocks themselves, all the blocks were approached in the same way - which involved an initial central placement. He had a general idea about centreing, at some level, but he did not try to judge the exact centre. This may have been implicit rather than explicit knowledge.

From the RR theory perspective, Remee is an anomaly. He had not encountered a similar balancing task before (according to his mother and playgroup leader), so would have been unlikely to have progressed beyond a stage of 'stable success'. His behaviour was not, in any case, dominated by a 'centre theory'. Remee was immediately successful

with the evenly and slightly-weighted blocks through operating with his 'implicit centre theory', but had reached a stage of 'stable failure' with the other two block types. What appeared to draw him out of his rhythmic repetition of failed attempts was the occurrence of something 'surprising'. This did not always lead him to success, but it did focus his attention on the problem and cause him to look for an explanation. This observation has two implications. Firstly, it indicates that he was anticipating (in a limited, local way) the behaviour of the block following his actions, this is a necessary prerequisite for him to be 'surprised'. Secondly, it suggests a possible stimulus for Representational Redescription. The notion of surprise as a factor in facilitating learning has been demonstrated in the animal literature, rats learn mazes more quickly if surprised (Lieberman, McIntosh, and Thomas 1979, cited in Lieberman, Davidson, and Thomas, 1985). Whilst this is not directly comparable to human behaviour, it indicates that the focussing of attention stimulated by the experience of surprise, may lead to a superior encoding of the situation. The link between 'surprise' and detailed encoding may also be evident in the phenomenon of 'flashbulb' memories, where a surprising event is stored in unusual detail. Karmiloff-Smith has a problem accounting for how 'stable success' stimulates representational change, and 'surprise' might provide a potential alternative.

There is clear evidence of a rigidity in performance during failure. When Remeo can no longer generate different approaches to the task he just adopts a repetitive behaviour. However, he has not completely 'switched off', as is attention is drawn by any (accidentally caused) difference in the blocks behaviour, from the repetitive pattern. It is then the evaluation and encoding of this which determines whether any representational progress is made. Karmiloff-Smith and Inhelder

stress the encoding of results of actions in terms of success or failure. The encoding could be a far more subtle and important process than this, for indentifying the relevant variables.

### **5.1.2 Kelly 4:4**

Kelly (4:4) was able to balance all the blocks and was, thus, at performance level 4. As a young success, she would seem to be a candidate for Karmiloff-Smith's 'phase 1'. However, she did not achieve her success through executing compiled proprioceptive feedback procedures. Her performance was not consistent, but showed evidence of exploration of the task. She let the blocks fall through her hands, or stopped them as they were falling. These investigations led to the development of a slightly more effective strategy during the experiment. Her performance changed from fairly gross to fairly smooth adjustments, and she moved from a single-handed to a two-handed technique.

Contrary to the 'phase 1' hypothesis Kelly had some level of 'centre theory'. She always started in the centre, but quickly changed to a proprioceptive method, when this approach failed. First using one hand only, making fairly gross tapping adjustments, and finally using two hands at each end of the block to make faster and smoother proprioceptive adjustments. However, she did not seem to analyse the blocks in advance of placement and treated each block in the same way.

### **5.1.3 Conclusion**

The task for the youngest subjects was novel; they were not at ease with balancing. When asked, they claimed that they had not done anything similar before. Their mothers and playgroup teachers agreed that this was the case, although 'balancing' would have been an implicit part of

many other construction activities. They were basically learning to do the task during the session and had to be shown a block being balanced to understand what was required. They then mimicked the demonstrated performance and success for the youngest subjects was initially a pleasant surprise. They recognised that the goal state had been achieved, but seemed to have no insight into the variables affecting performance. They were, as Karmiloff-Smith observed, treating each block as an isolated problem and approaching each of them in the same way. Initially, failure provoked an investigation of the task materials, although the relevant features were not identified. When a repetitive failure pattern was established, a change in the character of that failure was noticed. This then prompted a reconsideration of the task and/or behaviour, although in Reme's case this did not generate any insight.

The children were actively trying to understand the task. Reme, looked at the base of the block for 'clues'. Kelly was feeling what was happening and developed a relatively smooth two handed proprioceptive technique during the course of the experiment. Kelly's awareness of the weight of the block (at one stage she asked "What's on [in] this block?") may have been necessary for her success, although she clearly had not analysed exactly how weight was implicated in the balancing process.

## **5.2 Five-year-olds and the 'centre theory-in-action'**

The level 1 children very carefully tried to judge the exact centre, and therefore failed to balance all but the evenly-weighted blocks. They were less successful than the younger children (4:3 to 4:8) with the unevenly-weighted blocks. They continually took the blocks off the bar and re-placed them at the centre. They kept trying to achieve the exact

centre, not allowing any consideration of other possible places of balance. Having tried centring the block a couple of times they would give up. In line with Karmiloff-Smith, behaviours such as pressing down on the centre of unevenly-weighted blocks, and pronouncements that unevenly-weighted blocks were impossible to balance were observed. As Karmiloff-Smith noted, their performance is clearly dominated by a 'top-down' concern with centred balancing, a 'theory' as she terms it.

The 5-year-old children performed less well than the 4-year olds, but they also persevered less. The difficulties with the blocks were not analysed, they were merely rejected as not possible. When asked about what was hard about some of them, they were inclined to answer simply that they're 'too heavy'. They were actively analysing features of the blocks, but not extracting the relevant aspects. Perhaps this could not be integrated with what they explicitly knew about balancing. One 'level 1' child did manage to analyse that *one side* was heavier than the other, but he didn't think there was anything he could do to counteract this problem.

The main difference between level 1 and level 2/3 children seemed to be that they explicitly verbalised their belief that things balance in the middle, and that there had to be the 'same on both sides'. This explicit 'theory' may have been gleaned from balance scale tasks which they had encountered in their school work. When asked what they knew about balancing they described the balance scale equipment and the items which they had placed in the balance scale pans, rather than any underlying principles. The most they could articulate about the process was 'it has to be the same'.

Karmiloff-Smith does not argue that the 'theory' in phase 2 should

be accessible to language. Here it clearly was, and it may well have been influenced by the school experience. This explicit knowledge was not necessarily a natural progression from the earlier approach to the task, but explicitly taught knowledge which dominated behaviour. Its dominance over normal 'problem solving' behaviour may have been due to this direct, unintegrated, linguistic encoding. The level 1 children did not explore the task, they knew a little, but not in a flexible form such that they were able to analyse the blocks along the relevant dimensions.

### **5.2.1 Joshua (6:0)**

Joshua (6:0) began performing at level 1, but following a demonstration by the experimenter was able to improve his performance. He tried each block in the centre, in a single balancing position with no adjustments, and thus managed even to fail initially to balance the evenly-weighted block. He was encouraged to persevere and having balanced the evenly-weighted block he then tried some small adjustments around the central point with the other blocks. After 22 brief attempts with the various blocks, the obviously-weighted block was demonstrated to him. The demonstration took place at the experimenter's end of the bar, so Joshua initially tried putting the block at that same end of bar, indicating that he had encoded an irrelevant feature of the solution. However, when this attempt failed he did then move the blocks further off-centre and was able to balance the obviously-weighted blocks and the slightly-weighted block. However, he refused to move off-centre far enough to balance the very-weighted block.



### 5.3 Eight-year-olds and successful performance

Success in the older children was not a homogeneous affair. Within our 100%-successful (level 4), 8-year-old-group, there were qualitatively different performances. These are illustrated by two case studies.

#### 5.3.1 Stacey (7:11)

Stacey (7:11) took a long time (3 minutes 40 seconds) to balance her first block which was unevenly-weighted. She was clearly dominated by the centre concept, only moving the block very slightly around the centre the point. She also tried pushing down the lighter side, an ineffective strategy for balancing, but which might have provided some information about the properties of the block. Quite unexpectedly, at one point, she moved the block off-centre, but failed to balance and returned to the centre. A short while later she repeated this move, and after the block was over-adjusted, so that the un-weighted side fell (a surprising event), she persevered with adjustments around the correct balancing point until she succeeded.

After this tortuous success with the first block Stacey dropped her centre fixation, although not the complete centre theory. All the subsequent blocks were balanced in less than 18 seconds. She still placed all but one of the blocks initially at their centre points, but then rapidly moved them towards an approximate balance point. Adjustments towards the centre were often excessive, bringing the block back into a symmetrical position, but the proprioceptive information was given priority and they were moved back again. The one (obviously-weighted) block which was initially placed appropriately off-centre, was adjusted briefly back to the centre before being balanced.

This dramatic improvement in Stacey's performance, from near

failure to success, does not fit in with the phase 2 to phase 3 transition proposed by RR theory. The 'centre theory' was modified, rather than replaced with a better, more inclusive theory. She had clearly not abandoned her concern with the centre because she over-adjusted in that direction rather than relying entirely on proprioceptive feedback. She also began placing each block in the centre, rather than analysing where the block should balance in advance, as Karmiloff-Smith's phase 3 children had been able to do.

Stacey's experience with the first very-weighted block led to a reformulation of her approach to the balancing task, and presumably also of her underlying representation. However, this was not an overwhelming change, but rather a partial one. She was able to use her new knowledge to generate a behavioural response to failure, but not as a way of analysing the blocks and predicting their performance in advance. Each block was still treated in isolation with the same centred approach being taken to all the blocks initially. This lack of analysis and prediction indicates a fragmentary knowledge of the task, this is also indicated by her comments which are similar to those of a phase 2 subject. When asked why some of the blocks were more difficult than other she said that some were heavier. When asked what she knew about balancing she referred to the equipment in the classroom and the fact that she had put weights in one side and stones in the other.

Interestingly Stacey's behavioural/representational change followed after a surprising result, the block being placed beyond the point of balance, such that it fell down in the other direction. This was not only a different behaviour from the block, but also provided new information highlighting another element of the symmetry of balancing (that things should fall equally on both sides), which has to be

incorporated with the centre theory.

### 5.3.2 Marina (8:1)

Marina (8:1), another 8-year-old, level-4 subject, showed quite different successful behaviour from Stacey's. She was clearly analysing the blocks before placing them and using the information to guide her performance. She had a fully integrated concept of balancing.

Marina began with a very-weighted block which she placed in the centre. She then picked up the block and said "I know why this one is hard, its got a weight in one end or something." She then put the block on at the approximate balancing point and balanced it quickly. When subsequently given the slightly-weighted block with the same appearance she examined it and said "I thought this was the second one<sup>9</sup> for a minute, but it wasn't." Having analysed the block, she then selected the approximate balance point and again balanced it very quickly. She was not confident of her ability to balance the obviously-weighted blocks - perhaps she was not able to analyse their features as simply a matter of weight, however, she still managed to balance all the blocks in less than 25 seconds each.

All the blocks were evaluated before they were placed on the bar, and put in an approximate position of balance. Minor proprioceptive adjustments were then made to balance the block. Marina clearly had a deeper understanding of balancing, and a more flexible approach to the task than Stacey. Stacey had changed her performance strategy, but perhaps not her conception of the problem. She had a strategy which worked, but she did not know *why* it worked. Perhaps a stage of stable

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<sup>9</sup> She is referring to the previous (very-weighted) experimental block, which had the same appearance. This was the first experimental block, but for her it was second to the practice block.

performance success would be needed before she could identify and isolate the relevant features of her success. A re-formulation of the knowledge, so that like Marina, she could predict the behaviour of the blocks in advance.

## 6. Conclusion

This chapter has indicated that the three phases associated with RR theory oversimplify the developmental progression observed here, and that reported by Karmiloff-Smith and Inhelder (1974). It has proved more fruitful to use the concerns of the earlier paper in understanding developmental change in this task. However, the balancing task does produce a rigidity associated with level 1 performance, where subjects are dominated by their top-down beliefs and do not exhibit either the active investigations or the perseverance of both older and younger subjects. Whether this is a *necessary* developmental stage, though, needs to be investigated through longitudinal studies. However, the explicit verbalisable theories about centred balancing do not accord with Karmiloff-Smith's idea of E-i level representation, which are not linguistic. The reasons for the stultifying effect of the centre theory seems to lie in its domination of other process, not as part of a representational progression. This dominance may, in fact, be a feature of its isolation from other knowledge.

Siegler's approach to balancing is not directly applicable to the results reported here. Richards and Siegler's (1985) characterisation of balancing behaviour as the acquisition and refinement of a rule set, does not capture the exploratory nature of children's behaviour. Nor does it explain the flexibility which emerges with the final stage, the apparent integration of knowledge which allows an overview to be

taken of the task. This progression from success on a task, as shown by Stacey, to the insightful success shown by Marina, illustrates clearly the development, 'beyond success' to flexibility which Karmiloff-Smith (e.g. 1992) is concerned to explain. However, this study does not find that the RR model provides the explanation for that phenomenon.

There seem to be two main factors to emerge from the case studies. The first being the importance of prediction and analysis. Children were constantly predicting the outcome of their interactions with the blocks, even in a general way. The development of the ability to analyse the relevant feature of the blocks, to anticipate the behaviour of the blocks and to plan behaviour is what differentiated between different levels of success (illustrated by the Stacey and Marina case studies). All of our subjects seemed to *anticipate* what the behaviour of the blocks would be and thus to look-ahead to some limited extent. This is indicated by their being surprised when their predictions were not realised. However, only the oldest subjects were able to use their knowledge, in a flexible way, to control their behaviour in *advance* of action. Planning difficulties have already been mentioned as a potential explanation of problems in the drawing task (chapter 3), and a consideration of the development of planning processes will follow in chapters 6 and 7.

The second related factor is the role of surprise, and of un-predicted outcomes in stimulating representational change. This is hypothetical, suggested by the observations made, but may be a useful approach to the issue of what motivates representational change. There is also some support for pursuing this idea from the animal literature, and the phenomenon of 'flashbulb memories'. As the issue of motivations for redescription will be shown to be problematic for RR theory (see chapter

5), 'surprise' as an alternative to 'stable success' merits further study.

## **7. Chapter summary**

A replication of the block balancing task has not provided any support for the RR model. There was not evidence of a stage of initial success, produced by the simple proprioceptive feedback procedures described by Karmiloff-Smith. The rigidity associated with 'phase 2' of the model was observed, but the explanation of the behaviour did not accord with the 3R's model. The rigid behaviour was also associated with a failure to persist on the task, and may indicate declarative knowledge held in isolation from other related knowledge, rather than a stage in a developmental progression.

The observational data indicate a progression from 'success' to 'flexible success' which illustrates the phenomenon with which Karmiloff-Smith, and this thesis are concerned. However, the development observed in this chapter related to the ability to analyse the relevant features of the blocks, isolating them from the irrelevant features and integrating them into an overview. Knowledge development is clearly implicated, but it might also reflect the development of planning. This view is pursued in chapters 6 and 7. In the next chapter the RR theory is considered from a purely theoretical perspective.

## **Chapter 5**

### **A theoretical evaluation of Karmiloff-Smith's Representational Redescription model.**

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#### **Chapter Abstract**

Following a dearth of empirical support for Karmiloff-Smith's (e.g. 1986) model, this chapter analyses the models from a theoretical perspective. The initial representational format, criticised in early chapters, is found to be even more problematic. It is criticised as inadequately specified in terms of the level of representation, and unworkable in terms of its proposed inaccessibility. Further problems are identified with the concepts of: implicitly, represented information within procedures; behavioural success; stability as the stimulus to redescription; and endogenous metaprocesses. The implications of removing these problematic concepts are discussed, and the basis for a new recursive model, to be developed in chapter 9, is proposed.

#### **1. Introduction**

In chapter 2 Karmiloff-Smith's representational redescription model was outlined and the three behavioural and four representational phases described. In chapter 3 the representation proposed by Karmiloff-Smith for 'phase 1' in her model was rejected, in relation to children's drawings. In chapter 4 it was also shown that there was no

evidence of a procedural representation. This is clearly just one part of the model and the studies do not licence the rejection of the complete model nor the underlying theory of representational redescription.

Karmiloff-Smith (1992) differentiates between the underlying theory of Representational Redescription and possible models under that theory. She argues that it would be quite possible to suggest different models, which still related to the underlying theory. However, all of Karmiloff-Smith's work, to date, has concentrated on one particular model which is one of serial redescription. The criticisms of the model, to be outlined in this chapter, suggest fundamental changes to the theory as well as the specific model.

Karmiloff-Smith's (1986) article provides the most detailed account of her model. In this chapter the complete model will be analysed in more detail, on a theoretical rather than empirical level. The 1986 paper will be quoted at length to avoid the possibility of misrepresenting the model. The most recent account of the model (Karmiloff-Smith 1992) is much less detailed than the description in 1986 paper, however, the model has not been changed in any fundamental way. The analysis will, thus, concentrate on the 1986 paper. Karmiloff-Smith (e.g. 1992) has related the RR model to connectionist approaches, which were not mentioned in the 1986 paper, these specifically relate to her conception of 'behavioural success' and will be discussed in section 3.3.

In the first part of this chapter the RR model will be analysed as if attempting to implement it as a computer program. Analysing it in this rigorous manner will highlight problematic issues and so aid the development of a new model. Karmiloff-Smith employs the computational metaphor, and argues for the benefits of a cognitive



science approach to development (Karmiloff-Smith 1992). However it was *not* her intention to provide a complete computational specification. It goes without saying, therefore, that the model will be pushed for details beyond those provided in the paper. The second part of this chapter discusses the implications of remedying the problems, and suggests the basis for a new model of representational redescription.

Karmiloff-Smith (1992) quotes Klahr's (1991) distinction between soft-core and hard-core modelling and happily places her work at the 'soft-core' end. Hard-core modelling is the implementation of theories as computer programs, soft core modelling being simple verbal descriptions. There is clearly a place, as Karmiloff-Smith argues, for the soft core approaches. However, progress in the 'cognitive science' paradigm involves other researchers taking a harder core approach in an attempt to test and develop the underspecified theories. The aim in this thesis is to move in this direction.

The examples used in Karmiloff-Smith's (1986) paper are linguistic, and, in fairness, these linguistic examples will be used and evaluated in this chapter. However, her claim is reiterated that the model is intended to have general application and criticisms of the model will include references to other domains. The example Karmiloff-Smith quotes in detail is the acquisition of the indefinite article in French which produces a u-shaped behavioural curve. French children initially and correctly use the word 'un' for the non-specific reference function, the numeral function (French uses "un" for both the "a" and "one" functions in English), the appellative function and so on. At a later stage they spontaneously produce non-standard linguistic forms to overtly distinguish between these functions: they still produce the indefinite article for the non-specific reference function (e.g. un

mouchoir = a handkerchief) but add a partitive when implying the numeral function (e.g. un de mouchoir = one (of) handkerchief). Later still they produce the correct surface forms, as they had done initially although, Karmiloff-Smith would argue, these would be generated from different underlying representations.

## **2. Problems with Phase 1**

### **2.1 Introduction**

In chapter 3 the proposed representation associated with phase 1 was addressed experimentally. Problems were highlighted with the idea that children's drawings are represented as compiled procedures. Karmiloff-Smith (1992 and personal communication) acknowledges the problem with using the term 'compiled' (see Chapter 3 and Spensley 1991<sup>1</sup>), but she does not change the requirement that I-level procedures should be entirely inaccessible. In this section the term compiled will be used, where Karmiloff-Smith has used it, but should be interpreted loosely to mean only 'inaccessible', in keeping with her reformulation (Karmiloff-Smith 1992). The problems discussed in chapter 3 about procedural representations will not be reiterated here.

Karmiloff-Smith (1986) characterises 'Phase 1' as the knowledge acquisition phase, dominated by data driven processes. The child is motivated by the goal of achieving 'behavioural success'. Newly acquired knowledge is stored as independent procedures, and

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<sup>1</sup> Karmiloff-Smith read and commented on a conference paper (Spensley 1991) containing the material from chapter 2. She also acknowledged the study in her 1992 book (although mistakenly attributing the study to 'Spencer'). Karmiloff-Smith's letter is reproduced in appendix 1.

subsequently successful procedures are immediately compiled. The phase ends with

"procedural success, i.e. when there is a match between the child's output and adult output and the child's output receives only positive feedback."

Karmiloff-Smith 1986 (p. 105)

The processes described as operating in phase 1 could be summarised as a simple flow diagram like figure 1 below.

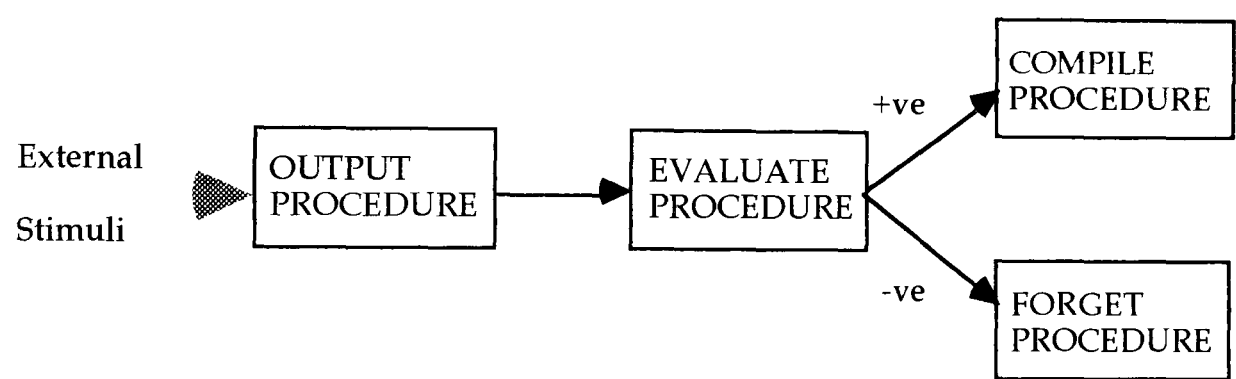


Figure 14. Flow diagram of processes operating in phase 1

External stimuli trigger the execution of a procedure. The execution is then evaluated in terms of success or failure at achieving the desired result, which may include feedback from external sources (although this is not essential in the model). A positive evaluation, i.e. a successful performance, leads to a procedure being compiled in memory. A negative evaluation leads to the procedure being discarded. Each new procedure example is stored as an additional isolated procedure and there is no way of relating the new procedure to other similar or identical procedures already in memory. Behind this apparently simple sequence, there are a number of underlying, interacting problems with this conception of 'Phase 1'. These will be addressed in turn in the following sections.

## 2.2. Generation of behaviour

A basic problem is the contradiction between the accessibility of procedures for the generation of correct behaviour, but their opacity and isolation in terms of storage. This is indicated by the lack of any circular connection in the flow diagram from compiled procedures to output procedures. It is essential for the child to recognise the appropriate context for the execution of a procedure, but the child is then unable to combine the result of the execution with the generalised representation of context which must have triggered it in the first place.

The fundamental requirement of the initial representational level in the model is that it must be capable of generating correct behaviours. The RR theory begins with 'behavioural success' and is only concerned to account for development beyond it. The first problem with the representation is that the correct procedures need to be called by something in order to be executed. In modelling cognitive processes this essentially means a context of use. The procedures in phase 1 of the model need something to enable them to recognise appropriate contexts in order to be successfully triggered. There need be no access to the contents of the procedure itself, but then the problem of access transfers to the *contexts* or conditions which trigger the opaque procedures. A possible example of an opaque procedure would be the author's 3-year-old daughter who has been taught to reply "I'm fine, thank-you" to the enquiry "How are you?". Her preferred response in such situations is to hide behind her mother's legs, so the complete verbal response has actually become a reflex, executed whilst she hides, rather than a meaningful communication for her. There may be no awareness of the role of the response, or the meaning of the words, but there has to be

recognition of the appropriate *context* to trigger the execution of this opaque response.

Phase 1 provides the model with a large number of independent compiled procedures, but it is not clear whether Karmiloff-Smith intended the isolated I-level procedures to relate to *instances* or *generalised* contexts. Either level is problematic for the model, as will be outlined below. The question of whether this type of representation is a reasonable outcome of acquisition processes in general is left open at this stage, (this will be discussed further in section 2.6).

The distinction between the instance and the generality is a fundamental problem in accounting for knowledge acquisition: the individual experiences isolated instances but develops general concepts. The difference is, for example, between using the word dog to refer to a specific 'token' of a dog (e.g. Fido who lives next door), or using the word 'dog' in a 'type' sense to refer to any instance animal in the class of 'dogs'. In a sentence context, this is the difference between: "I distrust my neighbour's dog" (specific token of the category 'dog'), and "I cross the road if I see a dog" (type, any member of the category 'dog'). In representational terms the former only requires recognition of the individual beast and labelling it 'dog', whilst the latter requires an underlying concept of 'dog'.

### **2.3 Levels of procedural representation.**

If the procedures are entirely opaque, then access to the contexts will not only be needed for executing the procedure but will also be needed to distinguish the range of different procedures over which the generalisation metaprocesses can later operate.

In the knowledge acquisition process the context could be encoded in terms of individual occurrences of an event, or grouped in some way into context 'types'. Karmiloff-Smith (at some stages) argues for no categorising of procedures, but it will be shown that at some level there *must* be a grouping process. Four possible levels of contextual description will be described for the procedures "utter the word 'un'", two of which Karmiloff-Smith seems at different stages to be proposing. None of them are satisfactory in terms of the model.

### **2.3.1 The instance level representation**

The instance level of representation would reflect the encoding of a separate procedure for every single context of use. Thus the French word 'un' in the linguistic context 'un chien', would be represented by a separate procedure for each instance in which it had been used e.g. a procedure for 'un chien' in the context 'dog I saw last Tuesday in the park at 2.30 pm'; another procedure for the context 'dog I saw last Tuesday from the car at 2.45 pm'. Similarly, separate procedures would be represented for 'un' in the linguistic context 'un chat' and again one procedure for each context in which it was used e.g. 'cat I saw last Tuesday from the car at 2.46 pm'; 'cat I am looking at now' etc. There would, *a fortiori*, be no differentiation of the various functions of 'un' which are later distinguished. Separate procedures would relate to the use of 'un' in 'un chien' to identify one specific dog of the dogs I am looking at now, or 'un' in 'un chat' to identify one specific cat of the cats I saw last Tuesday in the park 2.31 pm'. This level of representation would certainly generate a plethora of opaque representations, but the numbers would clearly be unmanageable.

If knowledge was encoded at this level of specificity there would be no possibility of generating new behaviours on the basis of old

behaviours. Every instance would be unique. No *identical* context would ever be encountered again, and there could, thus, be no basis for old procedures being triggered in new contexts. A child with such a representation could not use her knowledge, and therefore could not be behaving successfully as required by the model. There would be no basis on which to generate any new utterances of 'un' or anything else for that matter. This kind of encoding would leave a person able to absorb information about their randomly generated behaviours, but have no basis on which to act.

The instance level may appear to be something of a straw man, but it does seem to be the level advocated by Karmiloff-Smith at some stages in her description of the model. Following the successful evaluation of an instance, Karmiloff-Smith states that

"a new representation of the phonological form and its contextual use is entered into memory and compiled. At phase 1, such representational adjunctions are not evaluated with respect to the content of other entries. They are merely added to the plethora of existing entries, and there will thus exist multiple identical and/or slightly differing entries"

Karmiloff-Smith 1986 (p.105)

As no reference is made to the content of existing procedures in the evaluation process, it would seem that context would have to be defined in terms of the instance level. Such representation would certainly qualify for the term 'plethora', and would have the inaccessibility her model requires. Accepting any level above the instance level requires that some categorisation of the procedures (in terms of context of application, at least) occurs prior to compilation. In the model Karmiloff-Smith wants to reserve this type of process for phase 2 redescription.

There are other possible levels of description that could be applicable, and some of these are described in the next three sections. However, any level above the instance level necessarily involves some kind of grouping process. These groupings could be on the basis of semantic categories, or the linguistic context (function) of the word.

### **2.3.2 Category level representation**

A first level of categorisation could be in terms of grouping procedures according to their semantic context. For the 'un' example, this would mean one procedure for each specific noun regardless of function. Therefore, in the context of chien (dog) the word 'un' will be used for all instances of dog. A separate procedure will produce "un" in the context "un chat" (a cat or one cat), for all instances of cat. This would maintain the required 'plethora' of procedures, and provide a basis for generating the procedure on the basis of semantic category. The other advantage is that the basis for generating the procedure is not the functional one as that should emerge later through representational redescription. Beyond these features, though, there does not seem to be much reason for the child to develop representations at this level, rather than at a more general level.

### **2.3.3 Function level representation**

At this level of description only the function would be identified, i.e. there would be no distinction between semantic contexts. For 'un' there would be a limited number of procedures corresponding to the linguistic functions e.g. one procedure for 'un' in the sense of 'one' in English and one procedure for 'un' in the sense corresponding to 'a' in English.



In her concrete illustration of the model it seems to be the function level of representation that Karmiloff-Smith is referring to :

"My argument is that during phase 1, children develop one procedure for the non-specific reference function which outputs the phonological form of the indefinite article; another, independently represented procedure for the numeral function which also outputs an indefinite article (French does not differentiate between "a" and "one" in its surface grammar); yet another procedure for the appellative function which again outputs an indefinite article. In other words, at phase 1 the child has stored in memory a plethora of independently represented form-function pairs with respect to the indefinite article and its various functions."

Karmiloff-Smith 1986 (p.113)

However, this is not consistent with her frequent use of the word 'plethora' for phase 1 representations. There are a limited number of functions of a particular word. The idea that the instances are already categorised by function presupposes knowledge that is only, supposedly, implicitly represented in phase 1. The encoding processes must have used the functional distinction in building procedures in that format, even if this was not *consciously* processed. In phase 1 this distinction should not be explicitly represented, but should rather be implicit across a series of representations. Redescription by phase 2 metaprocesses is required for such distinctions to be represented and utilised by the child.

To avoid this problem it could be that here she is referring to the function-category level, this would allow for a 'plethora' of representations. The problem with the function-category levels is that, like the function level, it also presupposes the analysis of instances by function.

### **2.3.4 Function-category level representation**

A function-category level could be proposed which would take into account both the function of the word and the linguistic context in grouping utterances. Thus, there would be two separate procedures for using 'un', one procedure to identify an instance of dog, and another to identify one from a group of dogs, for example. Similarly, separate procedures for each function for cats and so on.

This level seems to fulfil some of the requirements of the Representational Redescription model, in that it would again generate a 'plethora' of procedures. Although, the number may still be unmanageably large. The functions are duplicated over a number of procedures, and therefore would require some rationalisation. Representational redescription metaprocesses could generalise over multiple representations for each semantic category. However, this level, like the category level, does seem somewhat contrived. It is hard to picture the acquisition processes which would lead to just so much categorisation, but no more.

### **2.3.5 Over-general procedures**

The final level to be considered is one that does not initially seem to fit with what Karmiloff-Smith (1986) has described. This level is the possession of a single, over-general procedure, which does not differentiate between the various functions of the word 'un'. Such a rule could, in theory, produce all and only correct behaviours without representing the implicit functional groupings.

This type of representation would not allow for the operation of the phase 2 metaprocesses as they are currently conceived. There would only be a single procedure represented, rather than multiple

occurrences. The RR model identifies the metaprocesses as operating on the procedural representations themselves. However, under this type of representation, the functional regularities would be implicit in the *behaviour* generated by the single procedure.

A successful 'over-general' procedure could be applied in a range of contexts, and the results of the execution of that procedure observed. The child could then extract the functional regularities implicit in her *behaviour* from the multiple occurrences. The generalisation metaprocesses would not then be operating on the procedural representation directly, but on the external behavioural output of those procedures. There would, however, be a plethora of 'execution instances' which would provide data for the metaprocesses (however, these instances could not be stored in an entirely unprocessed fashion, as mentioned earlier, due to limitations on reasonable storage capacity).

This reformulation would require a significant change in the representational redescription model. This approach requires a differentiation of the representations which *generate* the behaviour, from those which *encode* the results of the behaviour, and also from those which *perceive* the appropriate contexts and trigger the procedures. This elaboration is not unreasonable, and the three seem to have been conflated in the RR model.

However, the theory of Representational Redescription emphasises endogenous processes operating directly by accessing the generating representations, and extracting the regularities in these representations. To accept the 'overgeneral' procedure, the regularities would be implicit in the output, rather than the representation.

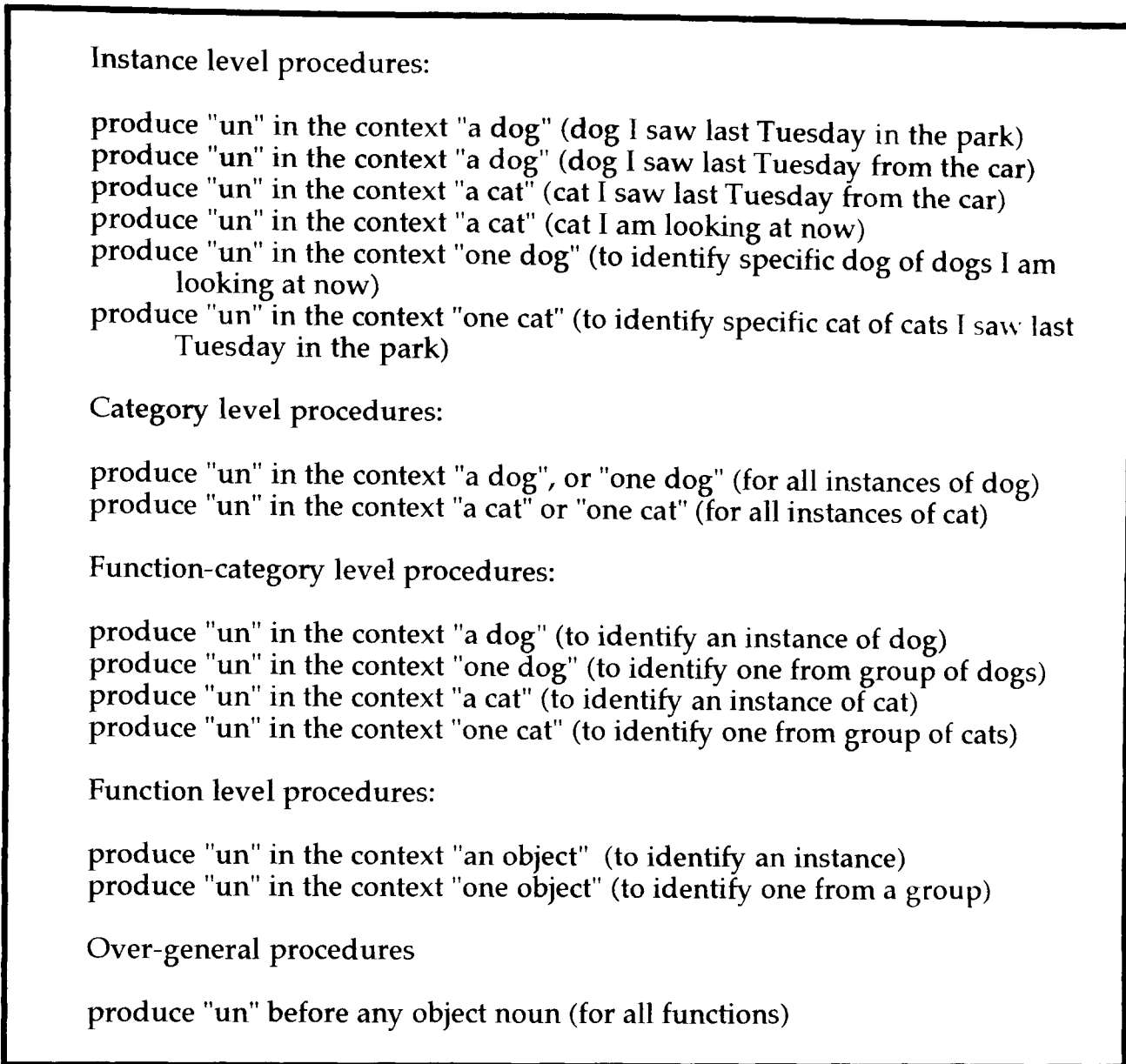


Figure 15. Examples of possible levels of procedural representation

### 2.3.6 Conclusion

The idea of a plethora of opaque procedures as the source of successful performance seems problematic for the model. It has been argued that the generation of behaviour, the recognition of contexts and the encoding of results should all be considered. The analysis of a new representational format for phase 1 should also be consistent with an account of how such representations would be acquired.

## 2.4 Evaluation

The second stage of the sequence of events highlighted in the flow diagram involves the evaluation of the child's output, to determine whether the procedure is compiled or rejected. The success or failure of a child's specific utterance involves

"a simple evaluation of match/mismatch between the present state (the child's output in a given context) and the goal state (the child's evolving representation of the adult output and of the context in which it is emitted). If there is a mismatch, the child receives negative feedback (via the internal matching process and also, at times, via social interaction, although correction from adults is not essential within this model). If there is a match between present state and goal state, then a new representation of the phonological form and its contextual use is entered into memory and compiled."

Karmiloff-Smith 1986 (p. 105)

This does not seem to be a 'simple' evaluation process as it presupposes what is trying to be acquired: the child has to already have a model of adult behaviour in order to evaluate whether her behaviour is 'adult' or not. The matching procedure is also problematic as the idea of an 'adult model' implies some general representation of appropriate contexts. Karmiloff-Smith stresses that the child's procedures at this stage are isolated, contextually bound instances, generalities can only be entertained following redescription.

## 2.5 Implicit information

There is a general conceptual problem with the idea of 'implicit' information being present in the representations. There must be some constraint limiting what is represented, so at some level any 'implicit'

information must have been selected as relevant to be represented (albeit unconsciously). This is similar to the problems outlined in section 2.2.1 with representing contexts at the instance level: if there is no restriction on what is relevant to be represented, then every single aspect of every single event must be represented. There will again be an information explosion. If there was no prior conception of what information would be relevant, then each instance of using the word 'un' would include irrelevant aspects of the context. For example, it might include a representation of the colour of the eyes of the person to whom the remark was addressed. This is clearly ridiculous, but reflects the impossibility of representational processes being entirely data-driven. All cognitive activities involve the interaction of top-down and bottom-up processes, and there is increasing interest in the developmental literature with the notion of 'perceptual constraints' operating from birth (Gelman 1990a). This will be discussed further in chapter 9.

Here again, the distinction is made between what is implicit in the *representation* and what is implicit in the *behaviour*. It may be better to conceptualise implicit information as a feature of a range of behaviours which has not been represented, rather than as inaccessible information which has been encoded at some level.

## **2.6 The problem of knowledge acquisition.**

The knowledge acquisition processes which precede phase 1 are peripheral to Karmiloff-Smith's model. However, the issue of acquisition needs to be considered in evaluating the plausibility of the representational format as the basis of phase 1 processes. Do children really acquire knowledge in a specific domain as a range of complete unanalysable procedures? Karmiloff-Smith does not align herself to

any particular developmental theory, but one which results in a plethora of unanalysed procedures generating behaviour must be a very passive process, largely data-driven process. Research in cognitive psychology is largely agreed on the conception of cognition as an active process of imposing structure on the world. There is a tendency to generalise, rather than to keep experiences separate and isolate. It is hard to see why children who may build up behaviours from their component parts would then render these parts inaccessible, apart from the automatisisation which accompanies highly skilled performance. It is not clear that this highly skilled 'automatisisation' is a precursor to flexibility within that particular behaviour (although it may allow other skills to be executed in parallel). This is not, in any case, Karmiloff-Smith's conception of phase 1 procedures. The question of acquisition processes will be re-examined at the end of the chapter (section 5.3), where it is discussed in conjunction with the problem of defining 'behavioural success'.

## **2.7 Conclusion - Problems with phase 1 representations**

The specification of the representation of the data is a basic requirement for implementing a computer program. Karmiloff-Smith is not clear enough on this issue, and attempting to isolate a possible level of description has led to contradictory requirements. The confusion at this level has implications for other aspects of her model, and it will be returned to later.

The idea of generating behaviour from a 'plethora' of representations goes against the general weight of knowledge in cognitive psychology. Humans tend automatically to generalise, to produce schemas and rules, and to group experiences into generalised representations. The idea of accumulating unanalysed instances is

therefore problematic. A shift of emphasis from information implicit in representations to information being implicit in performance may prove fruitful, but will also require a shift of emphasis from the purely endogenous processes proposed by Karmiloff-Smith.

**3. First redescription into phase 2**

There are a number of issues which are associated with the first redescription into phase 2 representations. They are the concept of purely endogenous metaprocesses, the concept of behavioural success, and the idea of 'stability' of a state as the stimulus to representational change.

**3.1 E-i level representation**

In order to continue to analyse phase 2, judgement must be suspended on the problems with the representation raised in section 2. Phase 2, like phase 1 depends on redescription of procedures in a certain format, so an over-simplified account will be proposed for the sake of argument. At the end of phase 1, ignoring all the issues raised in the previous section, the procedural representations might look something like figure 3 for one particular phonological form.

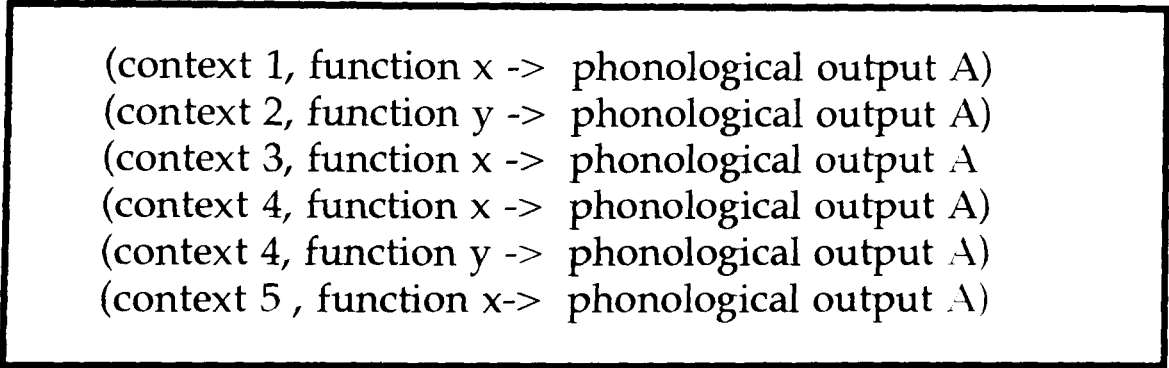


Figure 16. Phase 2 procedures



The procedures have a linguistic context and a function (or user's goal) which stimulate the production of a specific form and a compiled procedure for generating that phonological form. Whilst this looks plausible for the linguistic example provided by Karmiloff-Smith (1986), it would not be the same for the block-balancing task (described in chapters 4). The block balancing domain would contain entries with different contexts, but there would not be any differentiation of functions, as the goal of 'balancing' would be the same across procedures. Similarly, if the procedure was simply kinaesthetic in terms of a proprioceptive feedback loop, this would also be identical across different instances.

### **3.2. I- to E-i level redescription**

"Once each separate procedure for outputting the indefinite article has become automatised, compiled, and functions efficiently, i.e., is semantically and communicatively "successful" and receives only positive feedback, this stable internal state is recognized and the rewriting of I-representations into E-i form is set in motion. This is essential because I-representations are compiled and therefore their components cannot be addressed separately. The rewriting into E-i form makes it possible for analogies of phonological form and differences of function across the multiply-stored indefinite articles to be explicitly defined. Then the plethora of isolated form/function pairs can be linked, after which one form - the indefinite article - has plurifunctional status."

Karmiloff-Smith 1986 (p. 113)

The first level of redescription translates the I-level (Implicit knowledge) procedures of phase 1 into E-i level (primary explicitation) procedures. This phase is driven by the goal of 'control over internal

representations'. The E-i level procedures are more accessible, and the result is that the knowledge implicit at the I-level is available to unconscious access in phase 2. The redescription is carried out by metaprocedural operators, which construct the new representations without destroying the phase 1 compiled procedures.

"Constraints on the form of redescription involve a certain amount of loss of procedural information still retained in I-representations (e.g. information about the particular phonetic constraints on a particular form) but simultaneously a gain in accessibility of semantic/functional information."

Karmiloff-Smith 1986 (p. 107)

Once the E-i representations exist, another metaprocess, a scanning operation creates explicit links between E-i procedures with identical forms with different functions and identical functions with different forms.

There are some problematic concepts in phase 2, which will be discussed in turn. These are 'behavioural success' and the stability of that state, the evaluation of compiled procedures by metaprocesses and the definition of these metaprocesses. Karmiloff-Smith's notion that all these phase 2 processes are endogenous will also be discussed.

### **3.3 I-level to E-i level metaprocesses**

"After procedural success at the end of phase 1 for a particular linguistic form, a number of meta-procedural operators are set in motion during phase 2 which will enable the implicitly encoded representations to become explicitly related."

Karmiloff-Smith 1986 (p. 107)

Karmiloff-Smith is not specific about how the redescription of I-level into the more accessible E-i level procedures occurs. She just states that these unspecified metaprocesses are stimulated by consistent behavioural success in a particular domain and operate purely endogenously. However, this is not a straightforward process in implementational terms. The metaprocesses would have to be constantly scanning the knowledge base for domains which were ripe for this type of redescription (once the problem of recognising completed successful domains had been overcome).

Once a domain had been identified the metaprocesses would have access to a delimited range of successful, but opaque procedures. In order to generalise from these the first level metaprocedural operators must have some special access to the contents of the opaque procedures. How this is achieved is not specified. The resulting redescriptions are of a more general nature, accessible to the next level of metaprocesses, but the basis for the generalisations is not specified either.

### **3.3 Defining 'behavioural success'**

The stimulus to the first level of redescription is 'behavioural success'. This concept is central to the model as Representational Redescription is essentially a theory of development 'beyond successful performance'. A Representational Redescription program would thus have to have a clear definition of 'success' in order to redescribe procedures when the state had been reached. Success appears, at first, to be a clear criterion when applied to the language domain: either the child produces the correct linguistic output in the correct context or she does not.

However, as was outlined in chapter 3, it is a very problematic notion in less clearly defined domains such as children's drawings.

Karmiloff-Smith attempts to define 'procedural success' thus:

"when there is a match between the child's output and adult output and the child's output receives only positive feedback."

Karmiloff-Smith 1986 (p. 105)

However, this definition raises problems even in the language domain. The child will not necessarily reach both these states at the same time. The child may receive only positive feedback when the output is merely communicatively adequate, in the 'un' example, this may be before the child even uses determiners. Children are not continually corrected once they are understood. Far from it, many parents actually revel in their young children's linguistic idiosyncrasies!

The issue of feedback is quite distinct from the second part of the definition when a match with adult output is required. For matching to occur, there must be a model of adult output available to provide the basis of the comparison. It is not clear where this model would be or how the matching would occur. It cannot be a purely endogenous process otherwise it presupposes that the child already possess the adult model.

Karmiloff-Smith (1992) has suggested that 'behavioural success', might correspond to the stabilization of the weights in a connectionist networks. A network moves from continually adapting the weights on its connection in response to each new input, to a state where additional input does not change the stable network. This does hold some hope of defining 'behavioural success', but there still needs to be some endogenous metaprocess which recognises the stability, though having

access to the network representation itself. In addition, it is not clear how a connectionist account of the initial representation, would link to the higher levels of redescription, and Karmiloff-Smith has not elaborated this account. This hypothesis will not be pursued in this thesis.

### 3.5 Stability as the spur

For a system to recognise that it is in a state of stable 'behavioural success', there are a number of criteria which must be fulfilled. The first is to define how many correct executions must occur before the system can be deemed 'successful'. This would essentially have to be an arbitrary limit in any implementation, as the concept is not defined beyond 'absence of error'. Karmiloff-Smith accepts that the concept is hard to define (personal communication, see appendix 1), but does not conclude that it may not be a useful concept. The latter position will be argued in section 5.3.

The idea of stable success when only consistent positive feedback is received requires the identification of a distinct domain to which the state can be attributed. As there is no access to the ever increasing collection of procedures, there is no way to delimit such domains. The identification of specific domains is essential given the 'phase' nature of the model <sup>2</sup>, which hypothesizes that different tasks will be ready for redescription at different times. Certain task domains need to be identifiable as ripe for redescription, when others are not.

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<sup>2</sup> Karmiloff-Smith distinguishes between her model, which is a phase model, and the traditional 'stage' models e.g. Piaget's. In her model children are at different levels on different tasks, although the phases are passed though in the same order for each task. Stage models imply that the child is at the same level for all tasks.

The I-level representations are isolated compiled procedures, with no cross-referencing as to the contents of the procedures. With this type of opaque representation - which Karmiloff-Smith states can even lead to multiple copies of the same procedures (Karmiloff-Smith 1986, p. 105) - there is no apparent way of either recognising whether a domain is complete or whether success is consistent across all instances within a domain.

If task domains were identifiable in some way, it might be possible to specify an implementation for the ill-defined idea of stable behavioural success. It could be that no new procedures are added to that particular domain over a certain number of successful executions. Successful procedures could be reinforced in some way for example, moved up a list. However, this would still require some arbitrary 'stopping condition' based on time elapsed or number of executions of a procedure, rather than some more coherent concept of 'success'. Behavioural success seems to be a difficult concept in general and in terms of implementing a system it would not even be 'hackable' without some segregation or categorisation of the I-level procedures into domains. The recognition of this state is the stimulus for the operation of the metaprocesses discussed in the next section.

### **3.6 Endogenous metaprocesses**

Phase 2 redescription is characterised as an endogenous process. Although, the possibility of external influences is acknowledged (Karmiloff-Smith 1992) the centrality of the endogenous processes is maintained.

"... it is the endogenous processes operative at phase 2, and far less the influence of exogenous factors in phases 1 and 3, that are the most relevant to representational change."

Karmiloff-Smith 1986 (p.104)

The metaprocesses which operate at this phase make explicit the information which was implicit across the range of compiled procedures. In the linguistic example this is achieved by the scanning metaprocess which notes the form/function relationships. The result of this redescription is a new representation with procedures grouped according to function with explicit links.

The problem of the initial representation and the knowledge explosion is relevant again here. The new E-i level representation is the result of the metaprocess extracting information from the plethora of procedures. The relevant information must, as the essential prerequisite, be present in the procedure. If the information explosion, outlined with reference to the 'instance level' of representation (section 2.3.1), is to be avoided then the function which forms the basis for the grouping must have been selectively encoded from the start. So 'function' must have been used at some level as a filter for selecting out of the broad experience what it was relevant to encode. Function cannot, then be something that emerges purely from observing representations, but is something that must be encoded from the start, albeit unconsciously.

This problem of the necessity of encoding the basis for generalisation poses a serious problem in the block balancing task (as described by Karmiloff-Smith 1984, and outlined in chapter 4). In this task the result of the phase 2 redescription is a 'theory-in-action' that blocks balance at their geometric centres. Such a theory could never emerge through an

endogenous redescription of I-level procedures. If the blocks are initially balanced purely on the basis of proprioceptive feedback, the kinaesthetic procedures would not contain the information that things in general balance in the middle. This information is irrelevant to success on the task in kinaesthetic terms. The idea that things balance in the middle is an *observation* of the *output* of the kinaesthetic procedures and is not present, even implicitly, in the procedure itself. Thus, the development of a 'theory of balancing' could not emerge from purely endogenous processes operating on the kinaesthetic procedures proposed as generating the initial success. The redescription process would have to include some exogenous information, encoding observations of the outcomes of executing the procedures. The data for a 'centre theory' would be implicit in the behaviour, and dependant on encoding the results of the actions (however, see chapter 4 for a re-evaluation of the block balancing task).

The processes which create the E-i level procedures will be quite different from the processes which created the original I-level procedures. Experience leading to initial successful performance is mediated through the perceptual system, and the representational process is based on information translated from that code. These metaprocesses would be creating representations from representations, and internal observation, which would not use the perceptual channels. A kind of 'internal eye'. This is quite a dramatic shift in processing, and it is not clear in evolutionary terms how this supercognitive mechanism would have evolved. It would be more plausible if the mechanisms which were responsible for the initial representation could also create the higher level representations, and such a possibility should be considered before positing a supercognitive system (this approach is adopted in chapter 9).



A further problem with the metaprocesses, as conceptualised in RR theory, is their status 'waiting-in-the-wings' for their stability cue. Karmiloff-Smith has criticised Marshall and Morton (1978) for using an 'awareness operator' in a similar fashion. However, she has just transferred the problem away from awareness to the metaprocesses.

#### **4. Second redescription to Phase 3**

The second level of redescriptive metaprocesses have the same problems as the first level. The same arguments against wholly endogenous metaprocesses, and stability as the spur to redescription apply here.

##### **4.1 E-i level to E-ii level metaprocesses**

"Once redescription has taken place in E-i form, those representations can then be scanned, and any form/function analogies and differences can be explicitly defined. The scanning operation will thus be sensitive to identical forms paired with different functions, and to identical functions with different forms. A process is then initiated such that E-i representational links are established and defined explicitly."

Karmiloff-Smith 1986 (p. 107-8)

Karmiloff-Smith is not specific about how her metaprocesses operate, apart from the 'scanning' operator which detects form/function generalities in E-i level procedures. However, this provides *some* basis for searching for generalities, which is entirely lacking in her description of the first level metaprocesses. She states that there are a *number* of processes, but she does not specify how many or even suggest an order of magnitude. If there are so many additional metaprocesses, then their function requires explication. It is not clear

whether the number of metaprocesses are serving different functions within the model, or if she just means them to scan the procedures for different analogies. If the latter is the case, she only needs one general purpose scanning metaprocess which would be easy to implement. An exhaustive matching process could find all the other procedures which contained the same particular part or parts of a procedure. This kind of scanning operation would identify groups of procedures, but the psychological validity is debatable. The process would be entirely data driven (though endogenous), rather than based on any top-down hypotheses and would certainly generate some irrelevant groupings. To take up an earlier example, a grouping of 'indefinite articles uttered by blue-eyed people' would clearly be no use at all. These irrelevant groupings would have to be evaluated and rejected. There is no evidence that this happens and in any case the processes which could 'evaluate' the relevance of these groupings would be better suited to filtering out the 'encoding' of irrelevancies in the first place. A more constructive grouping mechanism, though, would require the metaprocesses to 'know' in advance the basis for making the redescriptions. This would of course, vary widely across domains.

The scanning process highlights the problem introduced in section 2.3 about the level at which procedures are represented, and the problem of delimiting the domain over which scanning would occur. Karmiloff-Smith's linguistic example illustrates the existence of the same surface form of a determiner with different underlying functions, it is not obvious that this plurifunctional situation would occur for the majority of cognitive tasks. However, this would depend on how the function was encoded within the procedure. Across the range of balancing tasks the function would always be 'to balance', unless the *functions* (rather than the *contexts*) were represented as 'build a house';

'stack the blocks' etc. Without more detail of the representation it is not obvious that the scanning operation would achieve something in all situations.

## 5. Towards a new account of Representational Redescription

There have been a number of fundamental criticisms made of the RR model. These include the concept of 'behavioural success', 'stability' as the spur to redescription and the idea of entirely endogenous metaprocesses for redescription. The dropping of these elements if the RR model would have fundamental implications for the development of a new model. The detail of the representational format in the RR model (Karmiloff-Smith 1986) has been shown to be implausible (in this chapter) and unsupported experimentally (chapter 3) and will not be pursued any further.

### 5.1. Redescription processes

The emphasis on endogenous redescription processes has been criticised. A number of problems both in terms of what is initially represented in the I-level procedures, and the operation of endogenous metaprocesses have been described. The example of block balancing particularly argues against endogenous redescription of implicit information. The necessary information could not be extracted, because it would never have been present. The block balancing case indicates information implicitly in the *behaviour* rather than in the *representation* which generated that behaviour. Transferring the emphasis from endogenous process to perceptual and encoding processes also alleviates the problem of the information explosion. If the emphasis on endogenous processes is dropped, then the model

would not require the initial 'plethora of procedures'; a notion which has been shown to be problematic.

The RR model suggests that cognitive flexibility is the result of a completely new developmental mechanism which only operates after success. It has been argued that more parsimonious accounts should be rejected before additional processes are proposed. It is possible that the processes which created the first representations could also create subsequent redescriptions, this position will be elaborated in chapter 9.

## **5.2. Stability as the spur to redescription**

This has been described as a vague criterion. In chapter 4, it was suggested that 'surprise' might be an alternative 'spur'. This would be independent of success or failure, but would be based on the prediction of the outcome of action. This criterion would be consistent with an interactive, rather than endogenous, redescription process.

## **5.3 Behavioural success**

Karmiloff-Smith (e.g. 1992) has insightfully argued that development does not stop with the ability to successfully execute a task. Development beyond success leads to the development of the uniquely human flexibility to reflect on the task. Karmiloff-Smith is only concerned to account for development beyond 'success', although this limitation has been criticised in this chapter and elsewhere (Goldin-Meadow and Alibali, 1994). Karmiloff-Smith (1994) justifies restricting her account to this limited section of development maintaining that "... one researcher cannot do everything" (p. 737). However, her insight that development continues 'beyond success' and her argument that this is not accounted for by most developmental theories, does not entail different developmental mechanisms operating in these two

developmental periods. Treating this 'post-success' portion of development in isolation needs to be justified.

The first step in justifying a separate stage in development, would be the identification of a clear division between pre- and post-success behaviours. It has been argued earlier in this thesis that 'success' as a single developmental point within many domains is a problematic concept. In the development of drawing multiple levels of success in depiction were described (chapter 3), and even in the apparently clear-cut domain of block balancing 'successes' differed (chapter 4). This is equally true of other domains such as language where communicative adequacy and syntactic perfection will not necessarily coincide. Karmiloff-Smith (personal communication see appendix 1) has accepted that the concept is difficult to define, however she does not accept the conclusion, drawn here, that these difficulties indicate that 'success' is not a useful concept in a developmental model.

RR theory specifically aims to provide a restricted account of development beyond 'success'. If the concept of success is dropped, the question of how Representational Redescription relates to the rest of development is highlighted. Karmiloff-Smith (e.g. 1992) has rightly argued that theories which stress the role of negative feedback cannot account for development 'beyond success'. However, this does not mean that negative feedback accounts are the correct explanation of *pre*-success development, which would necessitate a different post-success theory. More generally, Boden (1982a) has argued against the notion that negative feedback is important for development. If negative feedback is not required to enable the child to achieve successful performance then, it will be argued, the same processes which precede success in any domain could also take the child beyond it (see chapter 9).

The difficult problem of defining 'behavioural success' is then not solved, but removed.

## **6. RR as a general developmental mechanism.**

Dropping the central idea of 'behavioural success' from the RR model, raises the possibility that Representational Redescription could be a more general developmental mechanism. A new account will be elaborated in chapter 8, but the implications, in general terms, of removing 'success' are elaborated in the next section. A more general RR account should encompass development from infancy to expertise. Neither of these extremes are discussed by Karmiloff-Smith. (This proposed continuum, of course, conflates learning and development, a position which will be justified in chapter 8).

### **6.1 Recursive RR**

If the idea of 'success' as the starting point for Representational Redescription is eliminated, then other aspects of RR theory must be changed - crucially, the distinct representational formats. The limited iteration of 3 redescriptions requires a specific starting condition ('success'), and ends with completely flexible, linguistically encoded knowledge.

This limited passage from opacity to awareness would place an upper limit on knowledge development. Once 'awareness' had been achieved, for example in the drawing domain, no further development is hypothesized. It does not, therefore, account for the differences in cognitive flexibility between expert and non-expert adults. It is hard to believe that the 8- or 9-year-olds who can flexibly fulfil the 'draw a strange man task' will not develop their man-drawing representations any further, particularly, if they later become skilled artists. The RR

model also implies a lower limit on representational development. It could not be applied directly to development in infants and very young children, particularly the development of linguistic representations.

The standard A.I. solution to this problem of limits would be to propose a *recursive* redescription process or sequence of processes. This removes the specific problem of defining starting conditions, although it creates others. A recursive process requires a more generally applicable redescription mechanism than the specific metaprocesses alluded to in the RR model. It also necessitates the dropping of the sequence of qualitatively different representational formats. Karmiloff-Smith (1992, 1993) has recently prefixed her description of the three phases with the word 'recurrent', although this change in the model is not explained. It is not clear how the passage from opaque representation to flexible representations and then back to opacity would be achieved in a 'recurrent' version of the model.

A new account of representational redescription will be developed in chapter 9. It will eliminate the problematic concepts identified in the chapter and will place representational redescription in a broader developmental context.

## 7. Summary

"... models do have a way of taking on an air of reality through sheer use and familiarity."

Flavell 1976 (p.234)

The RR model (e.g. Karmiloff-Smith 1986) was criticised in previous chapters on empirical grounds, and is criticised further in this chapter in terms of its internal coherence. The model has not provided the basis for an improved understanding of cognitive flexibility, it has been

argued that it is not consistent or plausible in a number of respects. In particular the concepts of initial procedural representation, endogenous metaprocesses, behavioural success, stability as the spur to development, and implicit information within representations, are rejected. However analysis of the model has indicated some modifications, the most fundamental of which, involves dropping the constraint of 'behavioural success'. This generates the hypothesis that representational redescription viewed as a recursive process could be a general developmental mechanism. This idea is developed in chapter 9.



## Chapter 6

### Planning development: a review

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#### Chapter Abstract

In previous chapters the Representational Redescription approach to the development of cognitive flexibility has been criticised. In this chapter and the next, a new perspective on the development of flexibility, is considered: the development of planning ability. A number of descriptive accounts are reviewed, however no clear developmental sequence is proposed, or developmental mechanisms identified. The 'internalisation' mechanism is the only one referred to, and this is considered further in conjunction with Isaev's model of planning development, which follows in chapter 7.

#### 1. Introduction

In the previous three chapters the details of Karmiloff-Smith's (1986) model have been analysed and various aspects challenged. This chapter diverges from the detailed consideration of Karmiloff-Smith's theory to consider an alternative perspective on the development of 'cognitive flexibility'. Rather than the repeated restructuring of knowledge representations, it might be that the development of general purpose *processes*, such as planning, might account for improvements in flexibility. Planning is an ability which requires 'cognitive flexibility'.

Whatever the domain, the relevant knowledge must be manipulated to form a plan, and the execution of the plan must be monitored.

In the earlier discussions of RR theory, the development of planning was identified as a possible problem. In the drawing task it was suggested that problems in completing the 'strange man' drawings could have been caused by the failure to anticipate the interactions of the modification with earlier parts of the drawing. In the block balancing task, the two levels of successful performance were distinguished by the ability of the subject to predict the behaviour of the block from an analysis of its features, and thus to *plan* the correct placement for the block. If 'cognitive flexibility' on both these tasks includes the ability to 'plan', then it is important to investigate whether it is the development of planning processes which is explanatory.

Friedman, Scholnick, and Cocking (1987) have labelled the two basic approaches to the question of what it is that develops in planning, 'the expertise model' and 'the 'classic developmental model.' These positions broadly reflect the view that development in planning reflects an increase in domain related knowledge, and the view that it is a general planning ability which develops, respectively. Pea (1982) and Brown and De Loache (1983) claim that planning is 'metacognitive' skill, but as mentioned in chapter 2 there is some confusion about whether it is a general or a domain specific ability from this perspective. The 'metacognitive' approach will not be considered in this chapter. The development of a generally applicable, higher cognitive process, would provide an alternative to a representational redescription approach. The 'expertise model' could be compatible with representational redescription, and would provide the basis for the development of a new RR model or theory.

In this chapter some of the psychological literature on planning will be reviewed in an attempt to establish a developmental sequence. The evidence will be seen to be scant and incomplete. The most detailed model in the area seems to be Isaev's (1985), in the socio-cultural paradigm, and this will be presented in the following chapter along with a replication of Isaev's planning experiment. The review in this chapter will conclude that the development of planning and flexibility within planning can be explained in terms of changes in the knowledge and its representation, i.e. the expertise model.

## **2. Definition of planning**

Definitions of planning vary from those which characterise any goal directed action as planning, to those who consider the conscious pre-determination of a course of action to be definitive. Some general definitions are:

"...the predetermination of a course of action aimed at achieving some goal"

Hayes-Roth and Hayes-Roth 1979 (p. 275)

"Planning is a complex form of symbolic action that consists of consciously preconceiving a sequence of actions that will be sufficient for achieving a goal."

Pea 1982 (p. 6)

'Planning is the use of knowledge for a purpose, the construction of an effective way to meet some future goal.'

Scholnick and Friedman 1993 (p.145)

Friedman, Scholnick, and Cocking (1987) argue that it is the element of 'lookahead' which distinguishes planning from problem solving in

general - a concern to predict actions, rather than an emphasis on immediate problems (although see chapter 7 for an alternative comparison). The essential elements, common to all definitions of planning are 'lookahead', and goal-directedness. These elements are not sufficient for defining a flexible plan. Flexibility will require awareness and some ability to consider alternative plans. The highest levels of planning clearly require flexibility in manipulating knowledge, and it is the progression to these higher levels that is of interest here.

Planning is a cognitive process which operates over representations. Planning cannot occur in the absence of some domain and goal. Plans may be stored, and old plans executed in new circumstances, but there must be planning *processes* which can co-ordinate these or develop novel plans. Planning is a general purpose function which operates differently in different domains:

"... different planning contexts make different processing demands ... a different developmental picture can emerge depending on the task chosen ... different people at different ages can approach the planning task in different ways in different contexts."

Scholnick and Friedman 1993 (p.146)

There are many distinctions and debates within the field, and different theories emphasise different parts of the process (Scholnick and Friedman 1987). In the following sections the psychological literature will be reviewed to find developmental sequences, as the basis for a comparison between the expertise and classic developmental models.

### **3. Types of Planning**

There are two types of planning: 'anticipatory plans' and 'opportunistic plans' (Scholnick and Friedman 1987). Anticipatory plans relate to those which are formulated entirely in advance and then executed. This may be an idealised conception of the process which applies to well-defined or limited tasks. This type of planning is tested in 'plan formulation' experiments such as Klahr and Robinson's (1981) which will be described in section 8. Opportunistic plans are those which are created in stages, on the hoof, during the execution of the relevant activity. Hayes-Roth and Hayes-Roth (1979) argue that this type of incremental planning is most representative of behaviour in naturalistic tasks. These approaches to planning both contain the necessary 'predetermination' of action, but just appear to differ in the scope of the 'lookahead', whether it amounts to the complete task, or just a part of the task. However, in both cases there must be an appreciation of progression towards a goal, and an overview of the complete task against which to monitor progression.

There have been many distinctions made within the domain, and De Lisi has attempted to produce a complete taxonomy of plans and planning. This is described in the next section.

### **4. A taxonomy of planning development**

De Lisi (1987) proposed a taxonomy of planning development. In this section the taxonomy will be critically evaluated as to whether it provides a basic descriptive account of the different stages of planning. De Lisi's developmental model will then be related to studies of planning by other researchers.

De Lisi (1987) has described four types of plans and planning which vary in terms of the relationship between the plans and their contexts, the differentiation of the stages of planning, and the role of symbolic representations in the process. De Lisi claims that the four types of planning form a developmental sequence, in that, as the child grows she will be able to engage in more advanced types of planning

The taxonomy aims to encompass both types of plans, types of planning and to describe a developmental sequence. The rationale being that these are linked; different types of plan require different types of planning, and that these develop together. The result of adopting such an ambitious remit is a rather superficial account of representation and, it will be argued, a fallacious conflation of planning situations and the associated planning processes. The taxonomy attempts to cover both behaviour and the underlying representation, but these are not necessarily directly associated. Karmiloff-Smith (1986) has argued persuasively that the same superficial behaviour could be produced by qualitatively different underlying representations.

#### **4.1 Type 1 - the 'plan in action'**

De Lisi describes type 1 plans as procedural rather than declarative knowledge. He argues that they are executed without any level of awareness, or any access to the constituent stages of planning.

"A 'type 1 plan' is defined as a sequence of overt behaviours performed to achieve an objective. From the subject's perspective, the underlying entity that orchestrates the sequence is purely functional and operates in a nonconscious, automatically regulating fashion."

De Lisi 1987 (p. 92)

This definition is clearly reminiscent of Karmiloff-Smith's phase 1, where procedures are executed without awareness or access to their parts.

De Lisi subdivides 'type 1 plans' into three groups 'voluntary', 'involuntary', and what will be called 'developed' type 1 plans. Involuntary type 1 plans are, prototypically, instincts. Voluntary type 1 plans include sensorimotor means-ends behaviours (Piaget 1952 cited in De Lisi 1987) and practical, trial-and-error problem solving. Mid-way between voluntary and involuntary plans, De Lisi claims, are habits or skilled motor sequences, e.g. driving a car or touch-typing which will, in this thesis, be referred to as 'developed' type 1.

It will be argued that these subdivisions do not easily share the same overall category. They would seem to have qualitatively different histories and underlying representations. Voluntary and involuntary type 1 plans have no acquired conceptual element, but the motor skills included in the 'developed' category were learned, and will have involved a conscious processing stage. These plans only became procedural and were able to be operated without awareness through some skill acquisition process and associated representational change. De Lisi himself argues that a conscious representation of these motor skills can be accessed if something unexpected interrupts the execution. In contrast, voluntary and involuntary plans never had a conscious representational stage and are not open to 'debugging' in the same way as 'developed' plans.

For De Lisi the three categories of type 1 plan have features in common. The planner is aware of a goal, and will execute a sequence of behaviours to achieve that goal. She is aware of success or failure at goal attainment, but is not aware of the planning process.

"In each case the model depicts the idea of an underlying, directing organization of overt behaviour without having attained the status of conscious, deliberate representation of behaviour and its regulation."

De Lisi 1987 (p.93)

In the case of instinct this is because the behaviour sequences are hardwired, with voluntary behaviours this is because a step-by-step rather than an overall approach is taken, and in the 'developed' case, it will be argued, that this is due to some kind of representational re-formatting<sup>1</sup>.

According to the brief definition of planning (section 2 above) type 1 behaviours do not constitute planning, as they do not include the conscious advance prediction aspect of planning which was central to the working definition. However, voluntary and involuntary type 1 plans may be classed as 'pre-planning' behaviours which are clearly related to the activities of interest and may precede them developmentally.

In terms of creating a developmental sequence we are concerned with voluntary type 1 behaviours, which are roughly equivalent to Piaget's sensorimotor schemes (Piaget 1952, cited by De Lisi 1987). Sensorimotor schemes are learnt, and they are acquired on the basis of instinctive behaviours: the innate desire to grasp things then develops with experience into the voluntary type 1 behaviour of reaching for an object. It could be argued that type 1 involuntary behaviours could be a developmental precursor of type 1 voluntary behaviours. But, the 'developed' type 1 grouping is quite distinct, these plans must have

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<sup>1</sup> The term 'representational redescription' is not being used here, as in this example the representation is becoming less accessible, whereas for Karmiloff-Smith Representational Redescription is always a process of increasing explicitation. However, the new model to be presented in chapter 9 will allow for both developmental sequences.



evolved from higher level plans. This means that the behaviours do not belong in the same category as pre-planning behaviours. For the emerging developmental sequence being presented in this chapter 'developed' plans will not be included within the type 1 categorisation. Type 1 will be defined as De Lisi's voluntary type 1 behaviours and distinguished from instinctive behaviours when discussing development.

## **4.2 Type 2 - the 'plan of action'**

De Lisi's type 2 plans differ from type 1 plans in that the behavioural sequence, in addition to the goal, is anticipated before the course of action is triggered. This, he argues, requires the presence of a representational component which is lacking in type 1 plans. Type 2 plans are directed towards immediate contextual problems rather than distant or hypothetical goals.

Although the plan and the goal are distinct, type 2 planners are limited by the lack of an overview. They do not have a distinct phase of 'recognition of the need to plan', and they are unable to monitor their performance. Any monitoring that does occur is carried out by a more capable other.

The examples De Lisi (1987) gives of type 2 planning are a novice playing chess, adult direction of a child's problem solving, and skill acquisition. Thus, De Lisi includes both novice planners, i.e. children, and experienced planners operating in novel domains in the type 2 category. If the same developmental progression is proposed, this is a wide ranging claim. It implies that the process of 'planning' depends on the development of domain knowledge, rather than the

development of a unitary planning ability which can then be applied to all domains. However, this distinction is not discussed by De Lisi.

De Lisi includes in his type 2 category instances where the subject creates the plan and those where the plan is communicated to the subject by a more capable other. That is, both cases where the representational component is 'in the subject's head' and those where it is 'in the head of someone else'. These seem to be quite distinct types of planning. Wertsch (1985) and Vygotsky (1962) amongst others would argue that these two types of planning form a developmental sequence. Vygotsky suggests that higher cognitive processes, such as planning, are first experienced inter-psychologically and are later internalised to control the subject's own performance. In the developmental context De Lisi seems to be proposing this thesis of 'other-regulation' and internalisation (see chapter 2 and 7). However, it is not clear whether this is also the progression hypothesized for adult novices.

### **4.3 Type 3 - the 'plan as a strategic representation'**

Type 3 plans are fully fledged plans. They use a representation of possible future courses of action, and the plans can be made in advance of the context of application. Each of the stages of planning are present and separate, the phases being plan recognition, plan formulation, and plan execution.

"Plan as a strategic representation. A deliberate, strategic representation of anticipated future states of the environment and behaviour sequences designed to deal with them. Subject is aware of each phase of planning, and represents relationships among formulations, executions, and goals."

De Lisi 1987 (p. 91)

This fully rounded planning process seems to be a significant advance on the type of supported planning proposed by type 2 planning. There is no account of the developmental progression from type 2 into type 3 planning, beyond the mention of 'internalisation'. A more detailed developmental sequence, in this tradition, is that of Isaev (1985) which will be considered in chapter 7.

#### **4.4 Type 4 plans**

De Lisi defines type 4 as the type of plan which is developed for a distant, contingent, or hypothetical goal. It is a high level of planning, where the creation of a plan is the goal of the activity. An example of such a plan would be the organisation of social services in the event of a nuclear war. The recognition of the need for such plans is central to the activity, in the clear knowledge that the event planned for may never happen.

De Lisi's type 4 plans will not be described further as they are only differentiated from type 3 plans by the nature of the goal. In terms of a developmental sequence the processes will be the same. Type 4 plans are generated to achieve a hypothetical goal, but if that goal becomes a reality subjects execute the plan in the same manner as a type 3 plan. In terms of the cognitive processes involved type 4 is not a qualitatively different form of planning from type 3. In both cases the planner is aware of, and in control of, all the component processes.

#### **4.5 De Lisi's developmental progressions**

De Lisi has identified four types of planning, of which the first three are of interest to us. He claims they form a developmental progression, but does not specify any mechanisms for the development of one type of plan. He briefly acknowledges the Vygotskian internalisation approach,

but it is not clear whether this is also proposed for development in adults. The range of tasks which are grouped under each type do not fit easily together, particularly in type 1 which includes both the most basic instinctive plans, and the advanced automatised plans associated with skilled performance. This conflation is due to attempts to account for development and to categorize all types of planning within the one taxonomy. As a result no mention is made of where 'developed' type 1 fits into a developmental sequence.

Another issue with De Lisi's account is that it is not clear if he believes that children acquire more advanced plans for more advanced tasks, or whether they learn to apply more sophisticated planning techniques to the same tasks. All his examples in each category are of quite different types of planning.

De Lisi claims that his taxonomy reflects developments in terms of four functions: (i) a shift from 'functional' to 'representational' planning; (ii) the distancing of planning from the context of execution; (iii) the elaboration of the representational component; (iv) the increasing differentiation of the phases of planning. These are interesting concepts, which we describe further below, but they do not seem to relate directly to the four categories of plan in his taxonomy.

#### **4.5.1 Functional-representational shift**

The ontogenetically earliest plans are purely functional. There is no representational component, they are just a behavioural sequence generated to achieve a goal. Later in development a representational component allows the behavioural sequence to be rehearsed in advance, and facilitates the consideration of alternative behaviour sequences. The representational component then decreases in

importance with the development of skilled behaviour: overlearned plans are executed without any reference to the representational component being required. Although, if the plan execution is disrupted in some way, the representational component can be accessed.

It could be argued that all activity must be generated by a representation at some level. The movement which is characterised as 'functional to representational' might relate to the development of flexibility in a given domain. This shift could be compatible with the representational redescription model, locating the change in the representational format.

#### **4.5.2 Relationship of plan to context**

Linked to the functional-representational shift is the relationship of plans to their context. Early plans are directly linked to their context of occurrence, both the instigation and the execution of the plan are dependent on the relevant stimuli being present. Later plans can be formulated in advance of events and to fulfil hypothetical goals. De Lisi hypothesizes that the separation of plans from contexts occurs on a continuum, but again he does not suggest any mechanisms for the developmental shift. Donaldson (1992) argues that development in general, involves a distancing of thought from context, and this progression may not be specific to planning.

#### **4.5.3 Representational component**

The ability to separate plans from their context is dependent on the development of a representational component, and the related developments of logical structure, mental anticipation, knowledge base and memory. De Lisi quotes Piaget and Inhelder (1958), and Spitz et al (1982) as having demonstrated that a more elaborate representation

facilitates plan formulation. However, he does not elaborate on the possible mechanisms for the development of the representational component, although he seems to be advocating a 'classic developmental', rather than an 'expertise' view here..

#### **4.5.4 Differentiation of planning phases**

De Lisi identifies three components of planning which he claims are fused in early plans: plan recognition, plan formulation and plan execution. Increasingly these components become temporally and functionally differentiated. At first they are merged in an undifferentiated plan, then the plan formulation phase is separated from the execution of the plan. The last phase to develop is the recognition of the need to plan.

#### **4.6 Conclusion**

The different developmental progressions advocated by De Lisi, although interesting in themselves, do not map easily onto his four planning phases. Contradictions emerge, rather than a unified model of planning development. The differentiation of the planning phases is the main component of De Lisi's shift from type 2 to type 3 planning, which De Lisi explains in terms of the internalisation of adult distinctions (following Vygotsky 1962). In contrast the 'function to representational shift' seems to describe an entirely different developmental sequence, which describes the progression associated with skilled performance that results in the 'developed type 1' plans. De Lisi does not suggest any mechanisms for the development of the representation component, although if he is relating it to skill acquisition it must include domain knowledge. He does not explicitly mention whether the development of a representational component

occurs on tasks where previously a functional approach had been taken, or whether the representational component accompanies totally new planning situations.

De Lisi's taxonomy attempts to provide an account of both ontogenetic development of planning, and that associated with skill acquisition in adults. It aims to categorise types of plans in conjunction with types of planning. This is an laudable aim, but no underlying mechanisms are proposed to unify the approach. The result is a rather fragmentary account, containing wide variety of examples which does not provide the clear developmental sequence. A clear developmental sequence would provide the basis for evaluating any proposed developmental mechanism whether 'classic developmental' or 'expertise' based.

## **5. Development of planning in naturalistic search tasks**

The transition between type 1 and type 2 planning, on De Lisi's account would relate to the emergence of planning. Wellman and his colleagues have looked at young children's behaviour in an attempt to discover the origins of planning abilities. They have used various search tasks and have distinguished between planful and non-planful solutions (Wellman and Somerville 1982; Wellman, Somerville, Revelle, Haake, and Sophian 1984; Wellman, Fabricius and Sophian 1985). Physically searching for missing objects was thought to be a naturalistic task which would be understood by even the very young. Wellman and colleagues have argued that there is a gradual progression from non-planful to planful approaches to the task.

Wellman et al (1984) carried out two search tasks which indicated that young children were able to understand the requirements of the

task, and to search systematically in supportive conditions. In their first task 2<sup>1</sup>/<sub>2</sub>- to 5-year-old children were required to exhaustively search 8 dustbins in 6 conditions (3 x 2 design). The dustbins were arranged in one of three patterns: a semi-circle, a circle, or a random pattern, and each pattern was presented in two lid conditions, either the lids of the dustbins closed automatically after having been searched or they stayed open. It was hypothesized that the arrangements of the bins would affect the ease with which children could keep track of their search. The semi-circular arrangement was thought to be the most supportive as it provided an implicit order of search, and both a stopping and a starting position; the circular arrangement suggested an order of search, but without defined stopping and starting positions; the random arrangement provided none of these supports. The 'lids-open' trials were hypothesized to be more supportive than the 'lids-closed' trials as they provided an external memory for which locations had been searched.

In terms of the exhaustiveness of their search the youngest age group (2<sup>1</sup>/<sub>2</sub>- to 3-year-olds) were able to perform as well as the older children in the most supportive conditions. In every 'lids-open' trial they searched all the locations exhaustively. However they were more redundant in their searches than older children in both the 'lids-open' and 'lids-closed' conditions. All age groups showed less redundancy when the lids remained open than when they closed automatically. All the children who searched systematically adopted an approximately circular strategy for all arrangements. As a result, the circular arrangement was found to be more systematically searched than the semi-circle, which was in turn better searched than the random arrangement. In the 'lids-closed' conditions, the systematic



arrangement of locations facilitated the youngest children in searching exhaustively, but did not help to avoid redundancy.

The oldest children studied on this task (4<sup>1</sup>/<sub>2</sub>- to 5-year-olds) were capable of searching exhaustively and non-redundantly in all conditions. The efficiency of the search of younger children depended on the availability of external supports and improved gradually with age. Improved performance in the most supportive conditions indicates that even the youngest children understood the *requirement* of executing an exhaustive, non-redundant search, but without the external support they were unable to *perform* it. Wellman et al (1984) do not suggest any explanation for the differences in performance, but it is possible that the explanation may be related to cognitive capacity limitations. The results indicate that the deficit was not a lack of knowledge about the task, but difficulties in terms of execution. The younger children were unable to keep track of their progress.

In their second task Wellman et al (1984) focussed on an issue arising from the child's ability to adopt a systematic search strategy: the goal of minimising distance travelled. They tested 3 to 5-year-old children on a search task which required them to find five Easter eggs which they had seen being hidden at different locations in the playground of their pre-school. The locations fell (loosely) into two irregular clusters on either side of the playground. The 'clustering' of the locations was not obvious to us from the diagram they provide (Wellman et al 1984, p. 476). The distance between the left-most egg in the right hand cluster and the right-most egg in the left hand cluster is about the same as the distance between the two eggs in the left-hand cluster. It is certainly not clear that children would perceive these locations as 'clustered'. The locations could be divided into those to the

left and those to the right of the child's starting position, but this analysis would only have relevance to a child who considered all the locations before moving, i.e. a planner. The goal of minimising distances in the task was argued by Wellman et al (1984) to be valid as the distances between locations were large enough to be salient to even the youngest children tested. Although it is arguable how much of a sanction running around a familiar playground would prove to be for young children, as this is a normal recreational activity for them. In fact, they found that the total distances travelled by each age group did not differ from chance, showing that either the children did not aim to minimise distance travelled, or else they did not achieve it.

Notwithstanding the criticisms of the study, all the children were found to traverse the playground (move between 'clusters') less than would be expected by chance. This *could* be because children planned to minimise distance travelled, but Wellman et al (1984) argue that this result could also be achieved by a 'sighting' approach, where children went from the nearest/most salient location to the next. In both cases, the cluster first examined would be more likely to be examined exhaustively before the playground was traversed to search the other 'cluster'. Wellman et al (1984) argue that the production of a sequence of actions which achieves a goal is not adequate evidence to conclude that a child has engaged in planning. The behaviour *could* be achieved by the preconception of a series of moves, or by a 'step-by-step' approach choosing each move only after the execution of the previous one based on considerations of immediate perceptual saliency.

In later experiments Wellman, Fabricius and Sophian (1985) described the behavioural evidence for different approaches based on the planning and sighting approaches by children. They distinguish

between two alternative 'sighting' strategies which are used by non-planning pre-school children: line of vision and proximity. These strategies involve searching the location in direct line of vision and the nearest location respectively. In each of these strategies only one move is considered at a time, in a 'step-by-step' approach. Older children consider all the locations and plan to use the shortest possible route regardless of these other influences.

Wellman et al (1985) used another search task to distinguish between planning and sighting behaviours. The task involved collecting three Easter eggs from three clearly visible white buckets and depositing them in a target red bucket. The locations of the white and red buckets were varied in order to isolate the factors which affected their search strategies. The children were asked to go 'the quick way', and again it was argued that the distances involved were large enough to be salient to pre-school children (around 28 feet between locations). The children tested were aged 3- to 5-years old. Wellman et al (1985) predicted that children who were able to plan a route would minimise the distance travelled. Those influenced by line of vision would first take the location straight ahead, and those influenced by proximity would take the nearest first. Wellman et al also considered the possible attractive or aversive affect of the target red bucket, but found that this was not a factor. It was then possible to predict the first moves by subjects using each approach on each of the the arrays illustrated in figure 17). The predictions are shown in table 4.

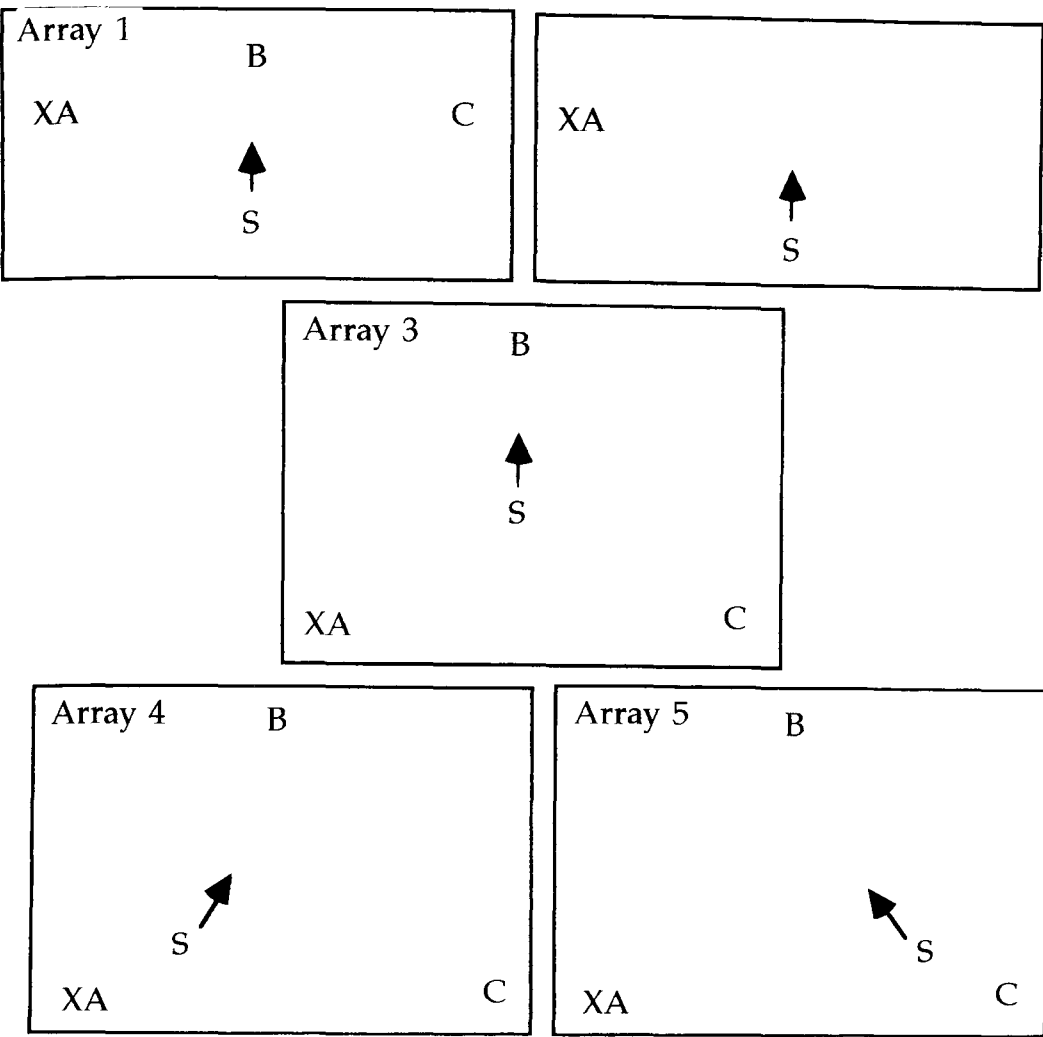


Figure 17. Five 3-location search arrays used by Wellman et al (1985). S indicates subjects location, arrows indicate subjects line of vision. X indicates end point.

Approach	Search Array				
	1	2	3	4	5
Planning	C	C	B/C	B/C	C
Sighting by line of vision	B	B	B	B	B
Sighting by proximity	-	B	-	A	C

Table 4. Predicted first moves on Wellman et al's (1985) search task.

Wellman et al (1985) found that the first move by all their subjects was based on sighting, with line of vision predominating: 66% of subjects moved to location B. Having moved to location B, subjects found themselves faced with a 2 move search problem in which neither location was straight-ahead and neither location was nearer than the other (see figure 17). However, a move to location C would avoid considerable backtracking. At this point the behaviour of the different age groups diverged: three-year-old children operated at chance level (51% choosing C), but both 4 and 5-year olds planned to avoid backtracks: 4-year olds 69% and 5-year olds 77% of the time.

In a follow-up study Wellman et al (1985) carried out a two location version of the task to investigate at what age planning dominates behaviour and replaces sighting. The two location arrays (illustrated in figure 18) eliminated the possible influence of line of vision sighting, and manipulated the influences of proximity-sighting and planning. The results, in terms of the first location searched by subjects in each age group are shown in table 5.

In array 1 the only possible influence on choice of location is planning. Children who are able to plan should choose location B. 3-year olds were found to behave randomly in this condition, but some 3<sup>1</sup>/<sub>2</sub>-year-olds showed evidence of planning, and the proportion of planners can be seen to increase with age. By looking across the rows of the table, the effects of planning and sighting, separately and in combination, can be evaluated. For the 4<sup>1</sup>/<sub>2</sub>-year-olds, it can be seen that the influences of both proximity and planning have an equal effect (guiding 73% of location choices) when they are the sole potential factor. When they reinforce one another (array 3) this percentage increases to 83%. However, planning does not dominate sighting at this age, and

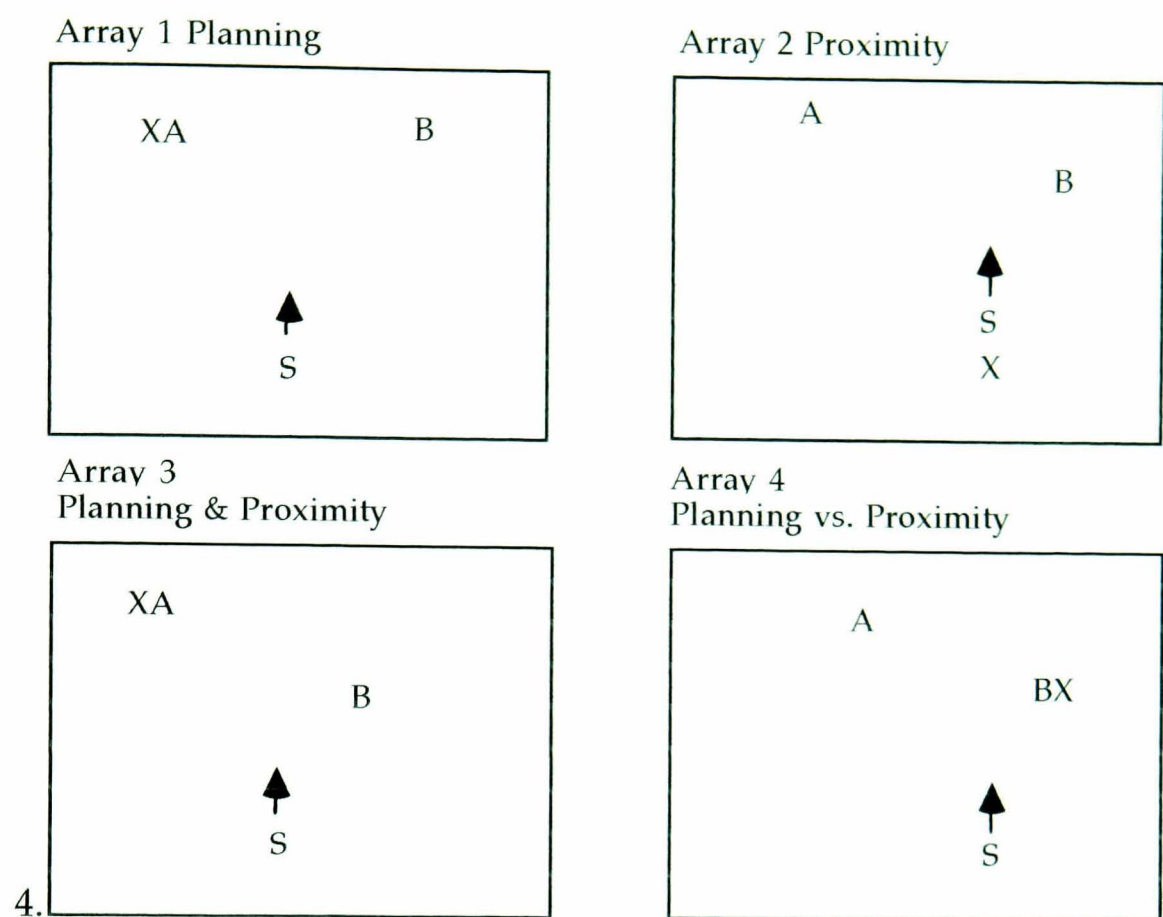


Figure 18. Four 2-location search arrays used by Wellman et al (1985). S indicates subjects location, arrows indicate subjects line of vision. X indicates end point.

	Arrays							
Age	1		2		3		4	
	A .	B.	A.	B.	A	B	A	B
3.0	.50	.50	.42	.58	.47	.53	.47	.53
3.6	.42	.58	.42	.58	.30	.70	.52	.48
4.6	.27	.73	.27	.73	.17	.83	.47	.53
5.6	.08	.92.	.62	.38	.08	.92	.88	.12

Table 5. First locations searched by age-group for the arrays shown in figure 18 (adapted from Wellman et al 1985)

when the influences conflict, as in array 4, performance decreases with only half the children (47%) taking a planning approach. In contrast, the 5<sup>1/2</sup>-year-olds maintained a strong planning effect in array 4.

The previous paragraph reports the aspects of the results that Wellman et al (1985) choose to discuss, but there are other factors which they do not mention. Their summary supports their conclusion that planning takes over gradually from sighting, but from this study there is no evidence that proximity is ever actually as strong an influence on behaviour as planning. In array 2 proximity is the only possible influence and those using that strategy should show a marked preference for location B. In fact, only the 4<sup>1/2</sup>-year-olds show a strong effect and, as argued above, they also show evidence of planning. 3<sup>1/2</sup>-year-olds show a slight preference for the proximate location, but like the 4<sup>1/2</sup>-year olds, this effect is not as strong as the combined effects of planning and sighting in array 3. The 3-year olds show no influence of planning in array 1, but produced the same result as 3<sup>1/2</sup>-year-olds on array 2, indicating an effect of proximity. However, if the 3-year olds are oblivious to planning, they should also show the effects of proximity on arrays 3 and 4, but instead they behaved at chance level. This casts doubt on the significance of the 42%/58% results<sup>2</sup> for 3- and 3<sup>1/2</sup>-year-olds on array 2, who may, in fact, have been behaving randomly. An unmentioned quirk in the results is that 5-year-olds actually seem to reject the proximate location in array 2, but Wellman et al (1985) do not comment on this result. There does not seem to be any support in these results for the idea that there is a stage where proximity-sighting dominates behaviour. It could then be argued that planning and

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<sup>2</sup> Wellman et al (1985) do not give details of the number of subjects tested in each age group and, as such, we cannot evaluate at which point the proportions reported differ significantly from chance. Their conclusion is that .42/.58 is a significant result, but it is

sighting develop together, and only later is sighting dropped in favour of a planning approach. Wellman et al (1985) might not have chosen the best task to support their conclusion, since in their previous study they found line-of-vision-sighting to be the most dominant influence, but, they chose to concentrate on the less influential proximity-sighting in this task.

## 5.1 Discussion

Wellman et al (1985) conclude a discussion of their studies by reiterating the conclusion from their 1984 paper,

"... young children's search processes represent a mixture of sighting and planning, with planning growing in dominance over the preschool years."

Wellman, Fabricius and Sophian 1985 (p. 132)

Their later experiments provided some additional quantitative results, but do not enable them to go beyond a purely descriptive account. There is no evidence that planning develops from sighting, only that sighting provides a transitory influence on search behaviour (possibly unrelated to planning), which at a certain age overlaps with the developing ability to plan.

All the children tested were successful on the tasks, which indicates that they understood and remembered the goal, although they either did not understand, or did not remember the means of achieving the goal. The studies carried out by Wellman et al (Wellman and Somerville 1982; Wellman, Somerville, Revelle, Haake, and Sophian 1984; Wellman, Fabricius and Sophian 1985) do not advance our

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questioned on the grounds that the numbers of children tested in their previous studies were not large.



understanding of how these approaches develop, how they are related to each other, or how they are represented cognitively. Wellman et al 1985 promise to elaborate on the two behaviours:

" In our current work (Fabricius, Wellman, and Sophian, in preparation), we have distinguished between planning and sighting more directly and definitively, by using search tasks especially constructed to contrast planned paths with those possible by sighting alone."

Wellman, Fabricius and Sophian 1985, (p. 128)

Sadly, the article that finally appeared (Fabricius 1988) did not have anything more to say on the topic, but provided instead more quantitative (but still descriptive) data.

Wellman et al (1985) justify the use of search problems as they are naturalistic. They argue that for young children planning may only appear in context, as a part of a specific task. They contrast their approach to that of Klahr and Robinson (1981, see section 7) which requires children to produce a plan in isolation from any activity. There is certainly a case for naturalistic studies, but at the current level of knowledge of planning development, the problems of isolating planning processes from other processes are immense. In relation to the underlying cognitive processes and representations, the naturalistic approach has not provided much information. In the section 7 the alternative "pure planning" approach of Klahr and Robinson (1981) will be described.

Wellman et al (1985) have outlined a possible developmental progression in terms of the goals and constraints which children's planning is able to address

"A possible developmental progression is from sensitivity to the need for and ability at formulating plans (a) designed to ensure success, to (b) those designed to ensure efficiency - in terms of the general constraints of effort - to (c) those designed to minimize cognitive costs, such as boredom. Such a progression, if verified, would help explain quite a few developmental differences in problem solving"

Wellman, Fabricius, and Sophian 1985 (p. 144)

However, using search tasks to identify planning development may be problematic in just these terms. Search tasks can *benefit* from planning, but they do not *require* planning to be successfully solved. Particularly with the low level of the tasks used in these studies the *need* to plan may not be obvious. Children may know that the task of collecting objects is achieved by picking them up one at a time, and not go further than that. Such a procedure will lead to success. What they may not appreciate is the *need* to plan, which is an arbitrary part of the request, or the fact that there are alternative paths possible. Children may have the capability to plan in a task that requires planning for success, but in these simple search tasks (as in many real life situations) a simpler step by step (or trial and error) strategy will work. Planning in these task depends on the the children relating their behaviour to considerations of *efficiency*, such as minimising distance travelled. Efficiency in such abstract tasks is basically a convention which has to be learned. These concerns are not central to young children, and running around a playground would not be considered a great sanction inducing them to plan ahead. This type of task does not tap the earliest planning situations, on Wellman et al's (1985) own account, those that require planning for success will emerge first. Thus, Wellman et al's studies may underestimate the age at which children are able to plan.

These studies provide some interesting descriptive data, but they do not provide clear data for either the classic developmental, expertise or metacognitive models of planning development. A possible interpretation of their results is that planning appears relatively late in search tasks, as the tasks can be successfully performed without planning. The application of a planning approach is dependent on the appreciation of arbitrary conventions on the method of being successful. Whilst this is very general knowledge, it might be the acquisition of this knowledge rather than the development of a general planning ability which accounts for the change from sighting to planning.

## **6. Development of planning in relation to general event knowledge**

This section describes a further naturalistic task, tapping the emergence of early planning, in a shopping task. Hudson and Fivush (1991) stress the role of general event knowledge and external environmental support in the development of planning. They argue that planning develops first in relation to familiar events, the representation of these events being organised as a generalised event representation (GER). GER's are script-like organisations containing the action sequences, temporally and spatially specified which constitute an event. However, GER's differ from scripts (Shank and Abelson 1977) in that the former provide the basis for planning whereas the latter are conceived as the result of recurring plans.

Hudson and Fivush propose 5 levels of planning in relation to GER's. At level 0, the plan is the GER. The child carries out the action sequence as specified in the GER, and therefore does not need to plan. Level 1, requires the child to fill slots in the GER. For example, the getting dressed GER will contain different items depending on the

activity planned, e.g. for a school day or for a party. Level 2 planning involves multiple goals. For example a 'going shopping' event, will draw on other GER's e.g. breakfast, lunch and house cleaning, to fill the 'select items' slots in the shopping script. These three levels of planning are suggested to characterise planning in pre-school children. The two higher levels of planning are level 3, co-ordinated event planning, where a set of independent events (e.g. shopping, laundry, fix the sink, make dinner) are co-ordinated into a sensible sequence. At the highest level, level 4, the action sequences are disembedded from specific GER's and the elements are reassembled to generate novel plans.

Hudson and Fivush (1991) used a shopping task to investigate children's progression between planning levels. They claim that this would more accurately reflect children's planning abilities than previous route planning (Gauvain, 1989, Gauvain and Rogoff, 1989) and maze planning tasks (Gardner and Rogoff, 1990). These shopping tasks, they claim, only require level 1 or level 2 planning whilst the novel maze and route planning tasks require novel plans to be generated, which means level 4 planning.

In the shopping task children had to select items for either a birthday party or for breakfast, or for both from a 'supermarket' of twenty items displayed on two bookcases. There were five items appropriate to each specific event, and ten distractors. After familiarisation with the 'supermarket', the children were asked to generate a shopping list (a plan) and then to execute the plan by collecting items in a shopping trolley.

There were two 'planning' conditions. Children were either asked to produce a (verbal) list of the items appropriate for one of the two

events, in which case they were subsequently asked to plan for the other event (successive condition) or they were asked to list the items for both the party and breakfast together (simultaneous condition). In all the conditions, after producing their list, the children were then asked to shop for the items. There were also two shopping conditions: either the relevant items were grouped onto the same shelf (clustered), or they were interleaved with the distractors. The former was a more supportive environment.

All the children were better able to plan for one event at a time, than for two events simultaneously on the basis of the number of items generated for each event. Four- and 5-year-old children generated more relevant items in the plan construction phase than the 3-year olds. In the shopping phase, 3-year olds tended to select everything, and were unable to use their plan except in the most supportive condition (the successive event condition with clustered displays). The 4-year-olds performed randomly on the least supportive condition (simultaneous with interleaved display), but were able to benefit from both the simpler task and the environmental support so that when both were present their performance equalled that of the 5-year-olds. The 5-year-olds shopped significantly better than either the 3- or 4- year olds and did not appear to be affected by either task or environment variables in their shopping performance.

The shopping performance was a measure of both advance planning and opportunistic planning, as children were able to select appropriate items which had not been explicitly planned for. A truer indication of advance planning ability was provided by the interaction of the planning and performance components, a measure of how well the individual carried out her plan, regardless of the merit of that plan.

The children were generally good at executing their plans, although performances improved with age and were again better in the successive than in the simultaneous condition.

In a subsequent experiment, Hudson and Fivush (1991) provided 3- and 4-year olds with support for their plan creation. The experimenter provided feedback on the appropriateness of an item suggested by the child, either in terms of event-consistency or the item's presence in the supermarket. The child was then reminded twice during the shopping phase, what the goal was. This kind of support was clearly helpful to the 4-year-olds who now performed at the level of the 5-year-olds in the previous experiment. The performance of the 3-year-olds improved and they showed evidence of following a plan, but they were affected by the cognitive loads imposed by the varying conditions. Thus, the memory load of the simultaneous condition, and the lack of support from the interleaved displays both decreased their 'shopping scores'.

## **6.1 Discussion**

The shopping task is a naturalistic one, recognisable and played as a game by many children. However, the game may be more common, and more elaborated, in five-year-olds than in 3-year-olds. The constraints of the task, to select only the items specified in a plan would not be a part of the normal shopping game, and these would require a novel perspective on their shopping and event knowledge. The breakfast and party events will have been experienced from a participant's point of view rather than from a shopper's perspective. Planning the shopping for these events involves adopting an adult goal. It is arguable whether they were really testing planning at levels 1 and 2, as they claimed. The task seems to require the generation of a novel (for the subject) plan, co-ordinating their shopping GER with

their breakfast or party GER, novel plans only being a feature on Hudson & Fivush's sequence of levels 4.

Hudson and Fivush (1991) seem to have three separate progressions involved in their single sequence, one in terms of the subjects' ability to engage in plans progressing up the GER knowledge hierarchy (level 0 to 1 to 3), and one in terms of increased plan flexibility, and the ability to co-ordinate multiple GER's at any one level (level 1 to level 2). The separate level 4, allowing for 'creativity' could apply to any level of the knowledge hierarchy. These distinctions will be clarified in the model to be developed in chapter 9.

Hudson and Fivush (1991) do not propose any mechanisms for the transition between levels of planning, which might have highlighted the problems with their transition sequence. However, they argue that the development of both event knowledge, and plan-monitoring skills might be implicated. They conclude that:

"... with increasing age and event experience, children become increasingly able to flexibly coordinate event knowledge in the service of planning ... [and] become less dependent on external supports to assist then in plan construction and execution."

Hudson and Fivush 1991 (p.414)

This conclusion, whilst convincingly supported by their results, does not help differentiate between different developmental mechanisms. Either an expertise view or a classic developmental view could be consistent with that result. The effect of environmental support was also found by Wellman et al (1984) in his bin searching task. However, it is not clear how children are benefiting, in cognitive terms, from the support, or if it is causally implicated in development. A potential explanation could be offered that it is processing capacity which

develops. In these situations it could be simply memory which is being supported rather than the planning process itself which is being 'scaffolded'.

## **7. Development of planning on a formal task: the Towers of Hanoi**

A 'plan formulation' approach to planning development was adopted by Klahr and Robinson (1981), who asked children to produce a verbal plan without actually executing it. The advantage of the approach is that there is no question of whether or not planning has taken place, as the product of the task is a pure plan. Klahr and Robinson (1981) tested subjects with a towers of Hanoi isomorph, and required them to generate a verbal move sequence. They were given no feedback on their performance which allowed Klahr and Robinson (1981) to capture a static picture of the planning level of each subject. Subjects were presented with tasks of increasing difficulty which, with feedback, might have lead to subjects improving their performance on the later tasks.

The task used (an isomorph of the 'tower of Hanoi') is less 'ecologically valid' than those described in the previous section and it has has been criticised on this basis (Wellman, Fabricius and Sophian 1985). However, the constraints of the task allowed a formalisation of the cognitive processes involved in the plan construction stage of the planning process. This kind of analysis has been lacking in the literature reviewed so far.

Klahr and Robinson (1981) quote Piaget (1976) as arguing that children of 5 and 6 years old cannot perform the 3 move tower of Hanoi problem<sup>3</sup> and can only succeed on the two disk problem by trial and

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<sup>3</sup> The basic tower of Hanoi task involves a tower of three rings, small, medium, and large, which have to be transferred from one of three posts to another. The restriction



error. Klahr and Robinson (1981) found this surprising as the two ring tower of Hanoi is a trivial problem merely involving the movement of the two rings to the goal peg in the correct order. This is equivalent to the type of two move problem solving performed successfully by infants (Gratch 1975, quoted in Klahr and Robinson 1981), and therefore well below the capabilities of five-year-old children on everyday tasks.

As the abstract nature of the original tower of Hanoi problem might have been a barrier to children's problem solving Klahr and Robinson (1981) used an isomorphic task with a plausible cover story. They also used materials which supported the child's observance of the rules and their memory for the goal state. Klahr and Robinson's isomorph involved moving three different-sized cans between the three posts. The ordering constraint of the original tower of Hanoi was built in to the problem as a smaller can could not be placed on top of a larger can as it would fall off. It was thus impossible to execute an illegal move. However, it was possible to generate an illegal move sequence, as the child was only describing a move sequence which was not executed. The three posts and cans were positioned opposite an identical set of cans which represented the goal state of the problem. The cover story involved a family of copy-cat monkeys (the large can was the father, medium was the mother, and small was the baby) who lived in three trees. These monkeys lived on the experimenter's side of a river. On the child's side were another family of monkeys who indicated the required goal state. The child's task was to instruct the experimenter in

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on the movement of the rings are that only one ring at a time may be moved, and a smaller ring must not be placed on top of a larger ring. The minimum move sequence for a three ring tower is seven moves. Problems with increasing numbers of ring are solved according to the same algorithm although the number of moves increases with a four move problem requiring 15 moves etc.

how to move her copy-cat monkeys so that they could be like the child's monkeys.

Klahr and Robinson (1981) presented the problem with a variety of initial and goal states, unlike the standard tower of Hanoi problem. This meant that optimal solutions varied from one move up to the seven move optimum of the traditional three-ring tower of Hanoi problem. There were two main variations in goal states in that some problems ended with the cans in the traditional tower formation (tower-ending) and some problems with the cans distributed one to a peg (flat-ending).

The problems were presented to 4- to 6-year old children in order of increasing difficulty starting with the one move problems. The child then progressed up to their own limit. After an initial familiarisation the subjects were not encouraged to handle the cans and instead were asked to direct the experimenter as to how she should move her cans. The experimenter did not actually move any of the cans or give the child any other feedback on her performance. The child was, thus, operating in a 'pure planning' mode and was not improving her performance during the course of the experiment.

Klahr and Robinson used Siegler's 'rule-assessment' methodology to develop profiles of potential strategies used by children. The profiles assumed three general principles for operating on the environment which, they argued, could be assumed to be possessed by all the children studied:

- P1: If you want object X to be in location B, and it is currently in location A, then try to move it from A to B.
- P2: If you want to move object X from A to B, and object Y is in the way, then remove object Y.
- P3: If the thing you are doing is too hard, then do some part of it that is easier.

Klahr and Robinson 1981 (p. 132)

The first two of these principles would normally develop during infancy, but the assumption of the third seems more problematic. Children may well operate on the principle 'If the thing you are doing is too hard, then get someone to do it for you or do something else'. The level of analysis required to distinguish a part of the problem which is easier may well be a later development. It also depends on the problem type as sub-goals are not always easy to distinguish. Children may well do something far more ad hoc before they are able to isolate a subgoal.

Klahr and Robinson created nine models of performance which have been specified in a MacLisp program. The nine models differed on three functions, (i) subgoal selection, (ii) obstructor detection and removal, and (iii) search depth, which were problem-specific versions of the general principles outlined above. Subgoal selection refers to the choice of the next can which needs to be moved to the goal peg. Obstructor detection and removal involves the identification of obstacles (which may be blocking either the 'from' or the 'to' peg) and the decision as to where to move the obstructor to. Search depth refers to the number of moves which can be planned ahead. An additional factor is the use of a simple means-ends analysis, evaluating whether a move has a 'positive goal gradient', i.e. if it results in more cans on the target peg. The models were created *a priori* and then related to the

performance of the subjects. They were used to analyse the behaviour of the six-year-old group and a subset of six of the models were found to closely mirror the performance of individuals across the problem set. The weakest subjects operated with models 1 and 2, the best subjects with model 9, and the mid-range with models 4, 6, and 8. It is this subset of the models that we will consider as a possible developmental sequence.

The models applied to performance across all the problems although they found differences in performance based on the goal state of the problem: 'tower-ending' problems were easier than 'flat-ending' problems. This was due to the clear sub-goal structure in tower-ending problems which was absent in flat ending problems.

Klahr and Robinson's models were compared with their subject's first move on each problem. They argued that because they provided subjects with a range of initial and goal states, the first move of any particular problem was the x-1 move on another problem. This approach was necessary because of their 'pure planning' task, without the child seeing their moves executed. Many problems occurred in the later moves due to memory problems, mis-remembering the current state, for example, which could not be disentangled from their planning performance

## **7.1 Weakest subjects**

The weakest subjects' behaviour could be modelled by two different models. Both these models move the smallest can which is not on its goal peg first. This means attempting to solve the most constrained problem first. This may reflect the fact that the smallest can is visibly the first problem to solve as it ends up underneath the others.

Model 1 reflects subjects' inability to operate within the rules. They have identified the goal, but attempt to move the cans directly to the goal peg regardless of any obstructions. This model is reminiscent of De Lisi's type 1 planners who are dominated by the goal of the problem and unaware of the processes involved in achieving it.

Model 2 works within the rules, but has no look-ahead and is dominated by physical salience. An obstructing can on the "from" peg is moved to free up the target can, with no consideration as to where the obstructor is put. The subjects do not anticipate obstructions on the 'to' peg, as they are focussed on the 'from' peg i.e. the first part of the move. This is similar to the 'step-by-step' sighting strategies described by Wellman et al (1985) in their search task.

## **7.2 Intermediate subjects**

Behaviour of intermediate subjects was consistent with models 4, 6, and 8. Model 4 showed the use of some means ends analysis, but they are limited to the extent that they can deal with the problems they detect. Subjects using this model have sufficient lookahead to move an obstructing can to the 'other' peg i.e. neither the "from" nor "to" pegs. However, they will not do this if this is an illegal move. Model 4 concentrates on the 'from' peg and will attempt to clear an obstruction here before it clears the 'to' peg if they are both obstructed. For example, on the problem (initial state 3/21/- to goal state 321/-/-)<sup>4</sup> a model 4 subject sees can 2 as the obstructor in this problem and chooses 2BC. On

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<sup>4</sup> The three sections separated by '/' refer to the three pegs. These are referred to as A,B and C, lettered from left to right. The cans are represented by numbers 3 being the largest and 1 being the smallest. The leftmost can is at the top of any particular peg. A move e.g. '3CA' refers to a numbered can, its starting and finishing location. In this case, the largest can is moved from peg C to peg A.

the problem (initial state 2/1/3 to goal state 321/-/- ) the model 4 subject would initially choose 2AC, but as it is illegal would produce 2AB.

In this model, as in models 1 and 2, the smallest can is attended to first. The subject is able to detect obstructors on both the "from" and "to" pegs. However, the subject gives priority to the "from" peg. The look-ahead amounts to only one level, enough to check the legality of an obstructor removal step.

Model 6 involves a limited depth first search of up to two moves. Using the subgoal ordering 1,2,3, the model 6 subject looks first for a single legal move that will get a can onto the goal peg. If there is no single move solution the subject will look for a two move sequence that will achieve the same result. On the problem (initial state 1/-/32 to goal state 1/2/3) cans 1 and 3 are on the correct pegs, and can 2 cannot legally be moved directly to its goal peg (2CB), so the obstructor 3 is moved (3CA) to the 'other' peg of the can 2 subgoal.

Model 8 is similar to model 6 but with greater search depth. It does a 3 level depth first search with the same sub-goal ordering. On the problem (initial state -/321/- to goal state -/-/321 ), the priority subgoal is 1BC, however, there is not a 3 move solution. The subject then looks for a three move solution for can 2 and moves 3BA and then 2BC.

### **7.3 Advanced subjects**

The most advanced subjects recursively attend to the minimum obstructor, by moving it to the "other" peg of the immediately preceding subgoal.

In the problem (initial state 2/1/3 to goal state 1/2/3 ), the subgoal 1BA is blocked by can 2. It is not possible to move can 2 to "other" peg

of the 1BA subgoal i.e. make the move 2AC, as C is blocked by can 3.. The next move considered is to move can 3, to "other" of the 2AC subgoal, i.e. to move 3CB. This is a legal move and so is the one executed. This model produces the minimum path solutions on all but 2 problems where one extra move is generated.

## 7.4 Discussion

The Klahr and Robinson approach provides an interesting analysis of some components of plan formulation, but the validity of the models may be open to question. There are only a small selection of legal moves from any particular problem state, and on the straightforward problems the intermediate and advanced models produce the same predictions. It is therefore only a small subset of the problems which become diagnostic. In any case, the fit with the models is only 70% at best, even when the comparison has been limited to the data from the first moves, of only the 6-year-old subjects.

The attribution of complete strategies is a little thinly supported by evidence from single move data. It may be that approaches to the problem are not so clear-cut, and would have an opportunistic element on later moves or that strategies would be changed if, for example, 'looping' behaviours were recognised.

The cover story of the problem was a vast improvement on the traditional abstract version. However, it was not a 'naturalistic' task for young children. The idea that the lack of feedback would provide a 'snapshot' of children's performance, assumes that children do not spontaneously progress without feedback. The children would be evaluating their own perceived performance, and might change their

approach even without external feedback. Karmiloff-Smith would certainly argue for such a developmental possibility.

Klahr and Robinson have implied a developmental progression between the different models, but there are no hypotheses about possible mechanisms for moving from one model to another. The main progression between models, though, seems to be in extent of lookahead, although there is also a development in strategies and analysis. They conclude

"Young children appear to have rudimentary forms of many of the problem-solving processes previously identified in adults, but they may differ in encoding and representational processes."

Klahr and Robinson 1981 (p. 113)

This study provides a useful perspective on planning development, and raises some issues which will be pursued in chapter 7. However, here again there is no mention of developmental mechanisms.

## **8. Conclusion**

Planning development is not well understood, this is amply illustrated by De Lisi's (1987) taxonomy which did not bring much clarity. This chapter has failed to produce a detailed developmental sequence, on a single task let alone a suggested developmental mechanism. All of the planning studies reviewed treat planning in isolation and none of them have been linked to a general theory of cognitive development.

Klahr and Robinson, have produced a developmental sequence with different levels of planning on the same task, which must be the fundamental basis for developing a mechanism. Otherwise, there have been no clear description of qualitatively different processes operating at



different age levels. This is confounded by a tendency to describe different types of planning with different levels of ability.

Hudson and Fivush (1991) had an interesting basis, with GER's, which could be developed, if the various factors within their hypothesized levels were considered separately. They were approaching planning development from the knowledge representation perspective, which, it will be argued, may actually be more informative than trying to isolate the process.

Planning development will be pursued in the next chapter, where a replication of Isaev's (1985) train shunting experiment will be reported. In this chapter, whenever a developmental mechanism has been mentioned, it is 'internalisation', so it is appropriate to consider a model in the socio-cultural tradition. This broader theoretical context recommends the work, and in addition Isaev provides a four stage developmental sequence for consideration.

## **Chapter 7**

### **Planning development: the Isaev-Magkaev model**

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#### **Chapter Abstract**

The development of planning was proposed as an alternative account to representational redescription, to account for children's behaviour on the drawing and block balancing tasks. In this chapter, one detailed developmental sequence proposed by Isaev (1985) is evaluated. A partial replication of his train task, with better controls is reported. The results, presented as case studies, produced evidence of the levels of planning proposed by Isaev. However, the subjects level of planning was shown to be related to domain knowledge, and problem representation, rather than to age. Case studies of adult subjects indicate that performance decrements with increasing cognitive load. It is argued that rather than the development of planning, the development of domain knowledge explains performance. Isaev's stages could be re-characterised as the interaction of problem representation and a limited capacity processor.

#### **1. Introduction**

In the previous chapter various descriptions of planning behaviours were described. These were presented as isolated pieces of research rather than as part of a broader developmental theory, or a complete

view of cognitive processes. They were also predominantly descriptive: a fuller account of the development of planning would include an account of the representations and the developmental mechanisms. The current chapter will focus on one particular approach (a composite of Isaev and Magkaev's models) to the development of planning which was developed in the socio-cultural tradition. From this perspective the developmental mechanism involved is internalisation. Planning as a higher cognitive process will have developed from the internalisation of social planning processes, which were originally used by others to guide the child's behaviour.

In this chapter the work of two Russian<sup>1</sup> psychologists, Magkaev (1977) and Isaev (1985), will be described, and a partial replication experiment reported. They view planning as an essential part of thinking in general:

"... the essence of human thought is the active transformation of nature in accordance with man's ability to foresee the results of his future actions."

Magkaev 1977, (p. 606)

Magkaev's (1977) and Isaev's (1985) articles appeared in the journal 'Soviet Psychology', and form isolated islands of translated research from a different tradition. The material specifically referenced in their discussions is not available in translation, so the full meaning of the terminology used cannot be appreciated. Any discussion of their work must necessarily be an interpretation. An attempt has been made to relate their work to other papers in the Soviet socio-cultural tradition (as translated by Wertsch), but the following description may be

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<sup>1</sup> Soviet citizens at the time of their studies, now Russians.

criticised for reflecting too strongly the author's western perspective. Many of the criticisms made in this chapter may relate to the different concerns and reporting formats of the Soviet tradition rather than to any inadequacies in the work itself. Nevertheless, the comparisons are worthwhile and informative.

The work of Isaev and Magkaev will be related to that discussed in the previous chapter. There are certain observations which link closely to points made by other researchers. Of particular interest here is the hypothesis of four developmental levels in planning, culminating in flexible performance. These levels provide an interesting basis for a comparison with Karmiloff-Smith's model as three of the levels relate to different behaviours in children who are *successful* on the task. As such the sequence of planning development could be related directly to her three representational phases.

## 2. Magkaev

Magkaev defines planning as the ability to consider alternative courses of action, which is more advanced than merely being able to produce a sequence of actions which will reach the goal. He identifies three major aspects of planning acts:

1. Planning acts constitute a mental search for as yet unknown but possible systems of operation (not the recall and mental reproduction of operations already acquired).
2. The search for these systems of operations is deliberate and intentional (intent or plan); their logical structure and the actual construction of that structure are the particular focus of the activity of the individual.

3. These systems are constructed on the basis of the individual's forecast of the results of future acts up to a specific point or "depth".

Magkaev 1977 (p.608-9)

This characterisation indicates a flexible planning process where the subject is able to consciously consider a variety of novel ways to achieve a goal. In a socio-cultural developmental context, it can be assumed that the planning processes have been extracted and internalised from previous experiences of the plans of others (e.g. Wertsch 1985). The limitation on the depth of plan generation mirrors one of Klahr and Robinson's (1981) considerations, and is an acknowledgement of the limited capacity of central processing.

Magkaev's experimental task involved presenting subjects with an array of 3 or 4 numbers as in the left hand side of figure 19 below and a target arrangement as on the right hand side of figure 19. The objective was to transform the initial array into the target array in the minimum number of moves. The numbers could be moved to an adjacent empty square, or could leap over one other number into the empty square. Numbers were not allowed to leap over two or three numbers, and only one number at a time could be moved, i.e. two numbers were not allowed to simultaneously swop places



Figure 19. Magkaev's number sequencing task.

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Subjects were given the problems in written form with a column of empty boxes corresponding to the minimum move sequence. Each movement of a number to the empty square was recorded by filling in the resulting number sequence in one of the empty boxes.

From children's performance on this task Magkaev identified four developmental levels of planning behaviour: (i) *manipulative*; (ii) *step-by-step*; (iii) *short-range* planning; (iv) choice of *effective* alternative. These are described in the following sections.

## 2.1 Manipulative

In order to solve the problems the subject had to have learnt the rules for moving numbers. *Manipulative* level children had learnt the rules, but in a formal way. They moved according to the rules, but each move was treated independently. There was no goal in terms of the final organisation, instead the intention was to demonstrate mastery of the rules. There was *a fortiori* no understanding of the requirement to complete the problem in the minimum number of moves. These *manipulative* level children operated within the relevant restrictions, but they were unable to solve the problem.

## 2.2 Step-by-step

*Step-by-step*-level children used the rules as a means to achieve the goal but without any internal or external testing of moves. There was little evidence of lookahead. Errors in terms of minimum move sequence were not corrected or even noticed. The subjects succeeded in achieving the goal, but ignored the minimum move requirement.

## 2.3 Short-range

Short-range planners were able to use a lookahead of three or four moves. They were able to correct legal, but non-optimal moves on the basis of the minimum-move requirement. However, they did not always seek out the most efficient solutions as a short-range plan, once formulated dominated their performance. At this level, external tests

of possible solutions were made in the form of pencil and paper sketches.

## 2.4 Effective

*Effective* planners made more external tests and sometimes made only mental tests. They considered more alternatives than short range planners and achieved perfect performance. These children did not show any evidence of looking ahead more than four moves.

Magkaev illustrated each level with an account of one individual child's performance on one problem. A different example problem was used in each case, which also restricts comparison of performances between levels. The descriptions referred to both the move sequence generated and to the children's comments. However, it is not clear which pieces of evidence were used to categorise the children. Ninety primary school children were tested individually, but the majority, 400 subjects, were tested in groups. Protocols could only have been taken from the individual subjects, and no account of how these were recorded or analysed was given. Thus, it is not clear how the subjects were assigned to one of the four categories from the purely written records which will have formed the major portion of the data.

Hypothetically, the written evidence could allow the following (rather basic) analysis to be made, in order to distinguish between behaviour types:

*Manipulative* - legal move sequence without success

*Step-by-step* - legal, but not optimal, move sequence to goal state

*Short-range* - legal, but not optimal, move sequence to goal state,

with some evidence of 'working out' plans.

*Effective* - legal and optimal move sequence to goal state

Magkaev's claim that these four types of planning form a developmental sequence is based on the percentage of children at different ages operating at the different levels. The percentage of children showing more sophisticated behaviours increasing with age. Transition between the stages was not discussed.

Magkaev characterised the development of planning as involving six functions. These functions being associated with plan generation, rather than the execution of a plan.

1. Connections were established among the elements of the situation, enabling the subjects to use the rules as practical devices for achieving the goal.
2. The subjects regarded changes in the situation and their effects as special, internal tools for achieving the goal.
3. The subjects envisioned the results of future actions, up to a certain point, before actually carrying out the operations.
4. Possible operations were distinguished and dealt with as relatively independent entities.
5. Operations were grouped together, and the subject operated with their overall result by abbreviated tests and envisioning the results of future actions.
6. The most efficient solution to the problem was sought and chosen (i.e., the instruction to find such a solution guided the subject's approach).

Magkaev 1977, (p.618)



There are two points which can be made here. The first point indicates a role for knowledge elaboration. This knowledge development issue will be discussed further in chapter 8, Chi and Ceci (1987) arguing that knowledge elaboration is central to development. The most interesting for our developing argument is point 5, that the lookahead is facilitated by the grouping of operations. This could be interpreted as chunking, a point which will be elaborated in the discussion section and in chapter 9.

### 3. Isaev

Isaev, who was a student of Magkaev's<sup>2</sup> developed Magkaev's sequence, emphasising the role of problem analysis in the development of planning (Isaev, 1985). He used a less constrained task and identified three basic approaches in the behaviour of 60 primary school children. These were (i) *manipulative*; (ii) *empirical*; and (iii) *theoretical*. Isaev's (1985) work appears to be a development of Magkaev's levels of planning and, as such, we have assumed that his three categories are also proposed as a developmental sequence. This is an assumption as Isaev does not explicitly make this claim in his paper and he does not provide any information about the distribution by age of his subjects into the three planning categories.

Isaev's planning task involved the movement of railway carriages in sidings, the objective being to rearrange the carriages into a target sequence in the minimum number of moves. The task is described in more detail in section 3.1 below. The problem required the subjects to

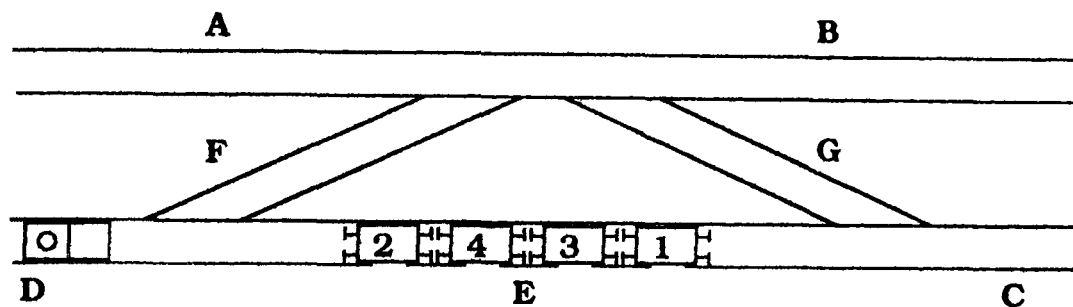
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<sup>2</sup> Rubtsov, personal communication.

restrict their consideration to the relevant tracks only i.e. to analyse the problem space.

### 3.1 Isaev's task

a) Initial order of cars



b) target order

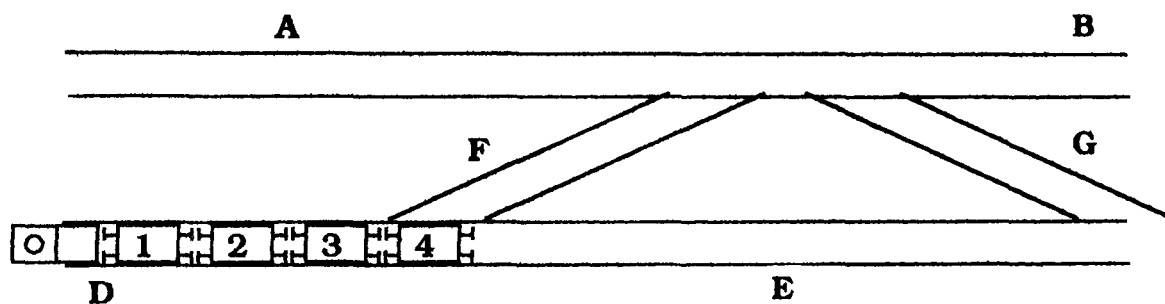


Figure 20. Experimental manoeuvring task, from Isaev 1985.

Isaev's task involved physically manoeuvring railway carriages in a siding using a model railway. The task was to rearrange the carriages into correct numerical order in the minimum number of moves. The carriages could be coupled and decoupled from each other at will, but they needed to be attached to the engine to move between sidings. The optimal solution to the example in figure 20 would be:

- (1) Split the train between carriages 4 and 3
- (2) Move the engine with carriages 2 and 4 attached to track B, detach carriage 4

- (3) Move the engine with carriage 2 attached back to track E, attach carriage 3, leaving carriage 1.
- (4) Move the engine with carriages 2 and 3 attached to track B, attach to 4 and detach the engine from all the carriages.
- (5) Move the engine back to track E, pick up carriage 1.
- (6) Move the engine and carriage 1 to track B, attach to carriages 2,3 and 4.
- (7) Move the whole train to track E.

Isaev's children were given three 'series' of tasks, although he does not state how many trials constitute a 'series'. The first series involved working with the toy train on problems involving three carriages; the second series involved four carriages with the task being presented as a 'drawing'; the third series involved five carriages with the task presented as a 'diagram'. In the latter two series the subjects were allowed to use the toy train if they desired (although it is not clear whether the train was set up for them in the relevant problem configuration). The essential differences between the 'drawing' and the 'diagram' condition was not made explicit, and it was not clear from the paper whether there was any hypothesized, or observed effect on the children's behaviour. Isaev states that the object of the first series was

"to determine how, specifically, the subject established the spatial-functional relations among the elements of the problem"

Isaev 1985 (p. 41)

and the object of the third series was to study

"... how the subjects constructed possible systems of rearrangements (i.e. the nature of constructing a plan of action)."

Isaev 1985 (p. 41)

No specific objective was stated for the second series. It seems that presentation type was confounded with problem difficulty in that the more complex problems were presented in a more abstracted format. These variables need to be controlled before any useful conclusions can be drawn.

Isaev based his analysis on data from sixty children "from the primary grades". The ages of the children were not provided and no information was given on the distribution of the sixty children over the primary age range. Isaev does not mention age in the context of his analysis of performance patterns, although the more advanced performances are attributed to 'third grade' children so it appears likely that the results form a developmental sequence. An analysis of strategy by age group would clarify this point. In common with Magkaev, no specific account of the transition between stages was proposed, although the internalisation process (Vygotsky 1978) is assumed.

The three basic approaches Isaev found were (i) *manipulative*; (ii) *empirical*; and (iii) *theoretical*.

### **3.2 Manipulative**

The *manipulative* category seems to be the same as the manipulative approach proposed by Magkaev. Children with a *manipulative* approach (10% of the children tested) were able to use the rules to move the carriages around, but did not seem to have a strategy. Their moves were unrelated to previous and subsequent moves, and they did not get the child nearer to the goal. Indeed, the child would forget the goal while manipulating the carriages. Support from the experimenter, in the form of a continuous dialogue, was required for the child to achieve the goal.

... the absence of single-mindedness in actions, which is the basis for establishing functional -spatial relations among the objects of which a task is made up results in manipulative solutions to maneuvering tasks.

Isaev 1985 (p. 47)

### 3.3 Empirical

The majority of subjects (83% of the children tested) used an *empirical* method. Subjects in this group were able to achieve the required result but did not do so in the optimal way. There were two subsets of the empirical method. The first subset labelled "planning thought in action"<sup>3</sup> contained subjects who planned only one step ahead. They would evaluate the situation after every move, alternating planning actions with external actions, but they were also dominated in their choice of moves by the obvious possibilities of the current situation. For example, if two carriages were on the same line they would immediately be joined up. Subjects in this group used all the tracks, having failed to identify that only a subset - those opposite the direction of movement of the train - were of use. This group is similar to the 'step-by-step' category of Magkaev.

The second *empirical* subset, similar to Magkaev's *short-range* planners did identify the relevant lines for using in the task and executed the plan in their heads, before moving the objects, but their routes were non-optimal. Like the previous method they were clearly oriented towards getting a result, but did not fulfil the requirement of using an optimal strategy to achieve it.

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<sup>3</sup> After Rubinstein (1946), a Russian language reference. The connotations of the term have, therefore, not been appreciated by the monoglot author.

The two *empirical* approaches seem to form distinct developmental stages. Isaev has reason to link them in that both approaches were result-oriented, rather than being concerned with the method by which the result was achieved, but there are also clear reasons for distinguishing them. The first subset seem to be dominated by the immediate context, while the latter were able to use a significant amount of lookahead. This may be an important transition in the development of planning reflecting a change in the representation of the problem. The two distinct categories suggested by Magkaev, *step-by-step* planners and *short-range* planners will be maintained to describe the two *empirical* subsets.

### 3.4 Theoretical

Subjects who took a *theoretical* approach to the task

"... viewed the situation as a holistic system of elements from the very outset."

Isaev 1985 (p.48)

They were able to take account of all the requirements of the task. The difference in approach between *theoretical* and *short-range* planners was evident in the four car task. (The three car task has only two or three possible solutions and so could not reliably differentiate the *short-range* and *theoretical* types). *Short-range* subjects stopped after they had achieved a result, *theoretically-oriented* subjects spontaneously continued trying three or four different routes until they found the optimal one.

### 3.5 The relationship of the Isaev-Magkaev model to Western theories.

The *manipulative* category in the composite Isaev-Magkaev model has a similarity with Klahr's model 1. Both found that 'pre-planning' subjects were not able to represent the entire problem. Isaev and Magkaev found that subjects forgot the goal of the problem, and in contrast Klahr found subjects were able to remember the goal, but not the rules. The difference in what was forgotten, reflects differences in the tasks. Klahr's goal was maintained for the subjects in terms of a visual model, they only needed to remember *that* this was the goal, not the contents of the goal. This visual presentation of the goal may have prioritised the goal over the rules, particularly because the moves were not actually executed. Isaev's 3-carriage task, in contrast involved physically manipulating the carriages, so the movement rules were paramount. The comparison of the two accounts leads to an overall impression of *manipulative* performance as reflecting capacity limitations in general, rather than a particular problem with maintaining the goal of the activity.

The Isaev's *step-by-step* approach is similar to the sighting strategies described by Wellman Fabricius and Sophian (1985) in their search task, which also proceed 'step-by-step'. As in the *step-by-step* category, children exhibiting sighting behaviour do not lose sight of their goal, although they do not look ahead more than one step at a time. Klahr and Robinson (1981) also describe a similar strategy which they call limited means-ends analysis. Their model 2 has some of the same characteristics as 'step-by-step' planning in that children plan only one move ahead and are dominated by the immediate possibilities of the situation.

Isaev's account differs from Magkaev's in that he sees planning as a derivative act of analysis and reflection, rather than a component of thought on an equal level with them. He also stresses the importance of the analysis of the task. This seems to be similar to Simon's (1978, Simon and Hayes 1976) concern with problem representation. This issue will be pursued in the discussion section.

#### **4. A partial replication of Isaev's train task**

##### **4.1 Introduction**

The composite Isaev-Magkaev account (hereafter referred to as Isaev's model), seems to offer a developmental sequence compatible with elements of the accounts presented in Chapter 6. The context of a socio-cultural approach also suggests (in very general terms) a developmental mechanism, i.e. internalisation. However, it seemed necessary to replicate the results due to the methodological problems with the original study. Isaev (1985) and Magkaev's (1977) descriptions of the behavioural levels are supported only with partial individual examples rather than with any overall statistical analysis. Additionally, there was no detailed account of how clear-cut the categories were, or of any problems allocating subjects to groupings. As a result, there is no basis for evaluating their validity or accuracy as developmental models. Their conclusions could not be accepted without serious reservations. It was therefore important to attempt a replication of the Isaev study, in order to evaluate the model.

Isaev's model assumes the development of a generally applicable planning ability. If this were demonstrated, it would cast doubt on the validity of any representational redescription (knowledge development)



approach to the development of cognitive flexibility. It is possible that the developments observed in chapters 3 and 4, in drawing and block balancing, could be explained by a planning development rather than by representational redescription. Isaev's three behavioural levels 'beyond success' cannot, from their account, be directly mapped onto Karmiloff-Smith's Representational Redescription model, although, the highest *theoretical* subjects are clearly able to adopt a more flexible approach to the task than those at the developmentally earlier stages. The train task will be a novel one to subjects, and Karmiloff-Smith does not deal with the issue of how children approach novel problems. A replication of the Isaev's stages should, however, provide a useful perspective on RR theory.

A partial replication of Isaev's train task will be presented in an attempt to illuminate Isaev's model. Isaev's task is more recent and his task is more naturalistic than Magkaev's, using a real train rather than an abstract manipulation of numbers. It should therefore be more appropriate for primary school children, who have limited experience with abstract problem solving. It also requires children to analyse the problem situation, and to limit their attention to the relevant tracks. However, both tasks include in the goal statement the requirement of completion within the minimum number of moves. This type of task has been criticised by Wellman et al 1985 who argue that it is not a familiar constraint for children (Anglo-American children, at least) and does not provide a good test of planning ability. An attempt was made to elaborate the minimum move requirement with a cover story, making it more readily understandable to young children. However, it remains an arbitrary constraint.

As mentioned in section 3.1, Isaev presented the more complex 4 and 5 carriage tasks in the form of a drawing and a diagram. This confounds the comparison process. In this replication, all the tasks will be given in the practical form as this was the most naturalistic format, facilitating the youngest subjects. From this approach it would be possible to compare performances between tasks of increasing difficulty, to distinguish the interaction between planning level (if this is a static processing feature) and task complexity.

Isaev's *theoretical* planning style describes a quite advanced, level of planning. In their studies, external memory was available to support this approach to the more complex problems. In this study, in order to compare performances between tasks of different complexity, the physical manipulation format is used throughout. It may not be possible for children to operate at the *theoretical* level on the more complex tasks. The problem spaces for the tasks increase by orders of magnitude in the numbers of possible problem states, and it may not be possible for children to adopt a *theoretical* approach to the harder problems. It seemed advantageous to have a 'top line' comparison to evaluate the solutions of the most advanced children against. In addition to testing primary school children, a small group of highly educated adults were also tested. These adults could be expected to produce optimal planning performances on the tasks.

## **4.2 Interventions**

Much of Isaev's account is based on the comments made by the children as they solved the problem and on the role of the experimenter in the process. Isaev provided verbal support if required during the interaction and also asked questions. The conditions for intervention, and the types of assistance given were not described, and may not have

been very systematically analysed. The general conclusions, for example, that *manipulative* children could not succeed without assistance were supported only by a single example protocol.

In order to define Isaev's planning levels more completely, and to look at the transition between stages, a replication will be reported in this chapter. A more systematic approach to 'scaffolding' the activity could provide additional useful information on the child's performance capabilities, particularly the nature of the "zone of proximal development" i.e. the level of the child's activity with the aid of an adult, and perhaps illuminate the internalisation process.

A systematic approach to interventions has been used by Wood, Wood, and Middleton (1977) and by McNamee (1987). Wood, Wood and Middleton (1978) identified five levels of intervention spontaneously used by mothers in assisting their children with a complex construction task. The levels are:

- (1) General verbal encouragement - e.g. "Good, now do something else".
- (2) Specific verbal encouragement - telling the child what to look for or how to proceed.
- (3) Selection - physical intervention to indicate the appropriate puzzle pieces.
- (4) Prepared material - orientation of pieces so that the child has minimal input to achieve success.
- (5) Demonstration.

Most mothers used a variety of levels at different stages in the task, but Wood et al found that the optimal approach to facilitate learning was to use all five levels contingently, following the rule

"If the child succeeds, when next intervening offer less help. If the child fails, when next intervening take over more control"

Wood, Wood, and Middleton 1977 (p. 133)

Similarly, McNamee (1987) used four types of intervention systematically in 'scaffolding' young children's recall of narratives. These interventions were, by the nature of the task, all verbal. They were:

- (1) Repeating the child's last utterance.
- (2) Asking general questions such as "what happened next?".
- (3) Asking specific wh- questions e.g. "What did the king do when the girl said 'No'?".
- (4) Providing the next piece of information by asking tag questions, e.g. "He went to see the girl's father didn't he?".

These studies indicate that it is possible to be systematic in interventions, and such systematicity could be employed in this experiment. In both these studies the experimenter intervened only when the child was stuck and could not proceed or if the child became distracted from the task. The types of intervention in both cases are determined by the structure of the task. Although both Wood et al (1977) and McNamee (1987) based their interventions on data collected from adult-child interactions, following from their findings it is possible to determine the levels of intervention solely on an analysis of the task. The experimenter in an experimental situation cannot interact naturally with the children, in the way a parent might in a play situation. The formalisation of interventions is imperative for any objective analysis of children's individual level of planning, or zone of proximal development.

From these studies we can abstract certain levels of assistance: in both Wood et al and McNamee's studies the level of least assistance consisted of general encouragement to proceed with the task, and the level of most assistance involved carrying out the next step for the child. The intermediate steps involved drawing the child's attention to various aspects of the task with increasing specificity, decreasing the amount of input that the child had to make to successfully complete the step. In the planning task these would involve narrowing the goal down to the specific next step. The proposed intervention sequence is as follows:

- (1) General verbal encouragement - e.g. "Good, now what are you going to do next?"
- (2) Recap on the goal - What are we trying to achieve?
- (3) Provide the goal.
- (4) Prompt for sub-goal - Which carriage do we want to move first?
- (5) Provide sub-goal.
- (6) Prompt for obstruction to sub-goal (if any) "What is stopping us from doing X?"
- (7) Identify obstruction to sub-goal (if any)
- (8) Prompt for next step - "What do we have to do to achieve X?"
- (9) Provide next step.

### **4.3 Experimental procedure**

Isaev's experimental procedure is described thus,

"Before the experiment was begun the basic features of the maneuvers were described in general outline.... The experimenter demonstrated that each specific assignment could be accomplished by different routings. Attention was focused on the main requirement of the task, namely, to find the shortest routing."

Isaev 1985 (p. 41)

From this description it is not clear what was demonstrated to the subjects, nor exactly what was said. It is not clear whether an actual target task was shown, or if it was possible that the subjects' behaviour could have been influenced by the alternatives shown. It is also not mentioned whether the goal of achieving the optimal solution included the target number of moves which appears to be the case in Magkaev's experiment, which might have made the 'optimising' solution more tangible for younger subjects.

## **4.4 Method**

### **4.4.1 Subjects**

Twenty primary school children from Harrold primary school, Bedfordshire were tested. Their ages ranged from 5:2 to 9:2, with equal numbers of boys and girls<sup>4</sup>. Four adult researchers (2 male and 2 female) from the Institute of Educational Technology at the Open University were also tested.

### **4.4.2 Apparatus**

A children's train set manufactured by 'Tomy' was used<sup>5</sup>. The carriages and the engine joined together with magnets, and were easy to join and

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<sup>4</sup> Sex was considered to be a problem in this experiment, because the use of a train would traditionally favours boys.

<sup>5</sup> The train set was selected because it was suitable for children of 3 years and upwards, and therefore relatively easy to locate in the tracks. The couplings are magnetic which

detach. The tracks were laid out in the arrangement illustrated in figure 20, each labelled section of track being long enough to accommodate the engine and five carriages. The top of each carriage was covered with a piece of paper (firmly attached) which bore a large numeral to identify it.

#### **4.4.3 Task Problems**

The problems were presented in order of increasing difficulty, i.e. 3-carriage, 4-carriage, and 5-carriage problems. Three problems at each level were presented to each subject, in a randomised order. The initial arrangements of the carriages in the 3-carriage group were 1-3-2; 3-2-1; and 2-1-3. The initial arrangements of the carriages in the 4-carriage group were a random selection from 2-1-4-3; 4-2-1-3; and 3-1-4-2. The initial arrangements in the 5-carriage problems were a random selection from 3-1-5-2-4, 4-2-5-1-3; 5-3-1-4-2; and 3-1-2-5-4. The target in each condition was to arrange the carriages in numerical sequence with carriage 1 next to the engine.

#### **4.4.4 Experimental Instructions**

The detailed task instructions and cover story used for this experiment are included in appendix 3. In summary, subjects were asked to re-order the carriages in the minimum number of moves. Alternative solutions, one long and one short were demonstrated. The justification for the minimum move request was that the carriages were full of eggs, which would break if they were moved too much. All subjects were asked to provide a verbal protocols whilst solving the problem.

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allows for relatively easy joining and separating of carriages. The train set also had the relevant track junctions, which were operated by points. The engine in this set may be battery operated, but batteries were not fitted during this experiment.

## 4.5 Results and Discussion

There were substantial problems getting the kind of interaction which was envisaged in the introduction. It was not possible to systematically prompt subjects because it was not easy to identify the point at which they were getting stuck. With hindsight, the reason is clear. Unlike the tasks used by Wood et al (1977) and McNamee (1987), Isaev's task did not cause subjects to stop when they did not know how to progress. Subjects meandered around the tracks and did not give any clues as to the exact point at which they should be interrupted. Problems with manipulating the carriages and changing the points led children to move round in circles. This behaviour was initially indistinguishable from the behaviour of children who moved round in circles because they had no plan and were awaiting inspiration. The proposed interaction with the subjects was not easy to achieve and was not systematically implemented. The attempt to implement this aspect of the experimental design was abandoned after a few subjects. However, it leaves open the question of understanding the nature of Isaev's interventions.

A number of behaviours, for example pausing, redundant moves etc. were analysed from the video-tapes, but there seemed to be little clustering of them in terms of the four planning levels, and there was considerable variation within individuals between tasks. The analysis of behaviours at the level of broad descriptions and clustering of behaviours seemed to obscure rather than illuminate the processes involved, particularly, as the performances changed over the course of the experiment. The unanticipated microgenetic development is confounded with increasing problem difficulty. Consequently,



quantitative analyses were abandoned and here, as in the block balancing experiment, a case study approach was adopted.

## 5. Case Studies

It was not possible to categorise the children's behaviours neatly into the four categories, and it became more informative to look in detail at case studies. One general factor which seemed to influence the relative success of subjects was their prior experience with train sets. Children were asked whether they owned a train set, and those with considerable experience performed better at a younger age. However, this experience is difficult to quantify: there is a large difference between the simplest child's train without even a track, and a complex electric train layout. Also, brothers and grandparents were reported as owning train sets and it was difficult to assess how much access the subject had to it. As a result, no quantitative support for this 'hunch' is offered. Nonetheless, those who were less experienced with trains or who reported simpler train sets (e.g. Duplo) did not have a conception of how the points worked, and were unable to predict the way that the train would be facing after a manoeuvre. They tended to repeat manoeuvres hoping that the train would not subsequently be facing the same direction, for example. This was consistent with Isaev's idea of analysis as the basis for successful planning, but it implicates the lack of background knowledge rather than a lack of analytical processes.

Children who had difficulties physically manipulating the train did less well on the planning task. This suggests that there was some interference, in terms of capacity limitations on dealing with these two problems at the same time. For these children there was a motor

problem, a conceptual problem with the interface, and a planning problem.

Predictably, none of the children managed to provide a complete protocol. However, a number of comments made by the most verbal young subjects are revealing. The majority of children were silent whilst they attempted to execute the task. The case studies to be reported were selected because they describe the most communicative children's behaviour, and as a result it was easier to analyse what they were doing. Three case studies across the age range are reported.

The adults studied did provide good protocols. Their performances provided a revealing level of comparison because they did not adopt a *theoretical* approach. A case study of the most successful of the adult subjects is also reported.

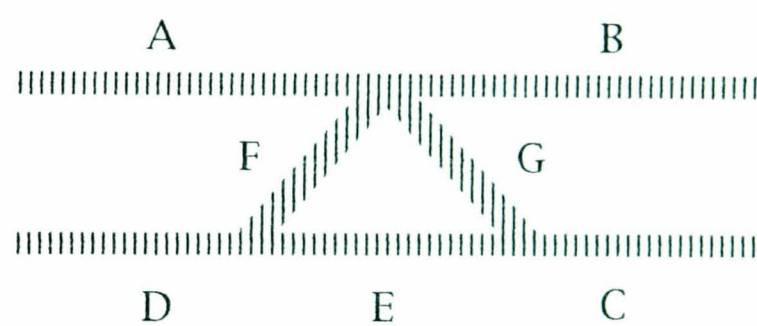


Figure 21. Track labels for the Isaev train task

A summary of the track diagram containing the reference letters is provided in figure 21, for reference whilst reading the following case studies.

## 5.1 Manipulative

### 5.2 Ben (5:2)

The youngest child tested was Ben, he has a 'Duplo' train set at home, which has a simple circular track. He might be considered to show a *manipulative* approach. Ben could not achieve the solution without considerable support from the experimenter, who had to prompt each step of the solution. He seemed to characterise the task as one of splitting up the carriages and then re-assembling them, in sequence. Initially, at least, he seemed to remember the goal, but he was unable to keep track of the apparently arbitrary movement constraints of the task. His initial approach was to pick up the carriages and re-arrange them into the required sequence. Ben wanted to turn the engine round corners, he wanted to pick up the engine and/or the carriages, and he wanted to move the carriages without the engine attached. He didn't know how to operate the points, and preferred to just force the train over the points in the direction he wanted it to go in, regardless. This method of over-riding the physical set up, then, did not restrict him from turning the train round the corners etc. eliminating the task constraint of backing the train onto certain tracks. The experiment was abandoned after the third three-carriage problem, during which he began setting his own agenda. He had latched on to perhaps the most subjectively meaningful aspect of the experimental instructions (that the carriages were loaded with eggs), and began loading his own imaginary items (cheese and burgers) into the train.

Ben had multiple problems with performing the requested task. He interpreted the train as a toy, which he just wanted to play with. In his first school year, this is perhaps not surprising. He could see how to solve the problem that was set, by picking up the carriages and re-

arranging them, and he didn't see the point of pursuing another (arbitrary) way of doing it. He had problems in physically manipulating the train, but the restrictions on the physical movement of the train (points and junctions) were ignored rather than understood and used to constrain the search for a problem solution. The restrictions on moving the train with the engine, and not picking up the carriages were just meaningless to him.

Ben's performance highlights how much there is to *know* in this task. The fundamental problem was with the social game of 'doing things an arbitrary way because you have been asked to do it that way', which is part of the school experience, but would still be novel for Ben. At Ben's age the conception of a train is a toy for putting people and goods in, and moving around. The idea that the engine provides the power, and as such is necessary to move the train did not seem to be central to Ben's conception. If this is so, rules which are transparent to older children and adults (e.g. you can't move the carriages on their own) are entirely arbitrary to a child like Ben. Ben's inability to succeed on various aspects of the task, indicates just how much knowledge is presupposed by it. He *could* have rearranged the carriages in his own way, but was not interested in playing the experimenter's game. It could not be concluded that Ben could not plan, but only that he would not accept the experimenter's conditions for planning.

### **5.3 Martin (6:6)**

Martin had an electric train set at home and was clearly quite at ease with manipulating the train: the train remained on the track, and he had no problems with the points, usually changing them in advance of movement over a junction rather than in response to a problem. Thus, the problem for Martin was one of planning. With the simple three

carriage problems, Martin did not use track E, the starting track as a location for leaving carriages. Thus, he is initially representing the problem as one which involves only tracks B and C as locations. On these problems he never even considered tracks A and D as locations. On one of the four carriage problems he did express a fleeting desire to leave a carriage on track A, but realised this involved turning the train around which was not possible. He seemed to have a complete understanding of all the relationships between the physical components of the task, he was able to perceive this directly without having to physically establish the constraint.

In response to the experimenter's request, Martin accompanied his performance is by an almost continuous description of his actions, e.g "I move this one up here, and then I move this one back here ...". He moved fairly slowly, but deliberately. He did not give any insight into his planning, except when he encountered problems. However, he clearly was predicting the outcome of his actions, as he was surprised by unexpected outcomes.

In the following discussion of Martin's performance (and for the other case studies), the carriages will be referred to by their numerals and the tracks by the letters given in figure 21. Tracks A and D are irrelevant, and track F and G are for transit only. Where a sequence of numerals appear, this relate to a group of carriages and their ordering on the tracks. The track arrangement only allows the train sequence to be backed onto a track, therefore a split in a sequence will allow the right-most portion to be left on a track. References to the engine will be kept to a minimum. All moves must be made with the engine attached, and the engine only attaches at the left end of a sequence.

With his first problem order: 1-3-2, the initial move was of the whole train from track E to track C. This is actually redundant given the problem statement, but not so if track E is not considered as a suitable location (This initial redundant step was also produced by some of the adults tested). Carriage 2 is then left on track C, the engine with 1-3 attached moves to track B where carriage 3 is then deposited. With carriage 1 still attached to the engine Martin collects carriage 2 from track C, then collects carriage 3 from track B. No plan was articulated in advance, and there was no apparent delay before he started moving the train. However, the task performance was fluid and apparently pre-planned, with a running commentary describing the moves made. The solution seemed to have been transparent for him.

Martin's second problem order was 3-2-1. Again his initial move was of the complete train to track C where, carriages 2-1 were left. The engine and carriage 3 were moved to track B where 3 was left. Martin then picked up both 2 and 1, whilst saying "then I pick up number 2" and moves them slowly towards track B. This may indicate that picking up both carriages was a slip of action (Reason 1979) rather than his intention. He hesitates as he move toward track B (where 3 has been left) and there is a break in his running commentary, indicating that something unexpected has happened. He then pauses to re-plan given the current situation. He then leaves only carriage 1 with 3 (1-3), on track B, and moves carriage 2 back to track C. This was obviously not the optimal move sequence, but each step was goal directed.

Martin prefaces his attempt at the third 3 carriage problem (order, 2-1-3), with the emphatically delivered comment "That is easy", and indeed he performed well on the task. In this case he seems to be building up from 3. These changes of strategy may indicate than he

does not in fact have an overall strategy, but is working from each situation as it emerges. There is no evidence of a *theoretical* approach, in that he does not consider alternative solutions once one has been perceived.

With the four carriage problems, some added difficulties emerge. There is evidence that he is 'thinking-in-action' in that he divides, then reconsiders, and joins carriages up again.

With problem 4-2-1-3 he moves all the carriages to track C, then leaves 1-3 (saying I leave 2 and 3, the experimenter then corrects him to 1 and 3). He then moves 4-2 back on to track B. He initially splits off the 2, but then reconsiders and leaves off the 4 as well. This may be evidence of conflicting subgoals. It will become apparent that he intended to join 1 and 2, and so perhaps he is also trying to get 1 next to the engine. He cannot achieve both these moves in one step. He returns to track C and collects carriage 1, having detached it and moved it slightly forwards he exclaims

*Martin: "Ah! Now that's a bit of a hard bit!" (pointing at the carriages 4-2 on track B, then continues moving the train).*

*Expt: Now that's a hard bit is it? Why is it hard?*

*Martin: 'cause its behind there (pointing at carriages 4-2 on track B)*

*Expt. 'cause its the wrong way round?*

*Martin: behind there, Yeah!*

He realises this problem, but hardly pauses because of it. He moves on to track B, picks up both carriages 4 and 2 and moves them back to track C, forming the sequence 1-4-2-3. He doesn't seem to have anticipated the construction of the 2-3 subunit, as his intonation reflects surprise

and delight when he notices it. He then leaves the 2-3 component on track C, deposits carriage 4 on track B, collects 2-3 and then 4, solving the problem directly and smoothly.

With problem 3-1-4-2, Martin initially moves all the carriages to track C and leaves 1-4-2. He moves carriage 3 to track B and then returns to track C. He collects carriage 1, splitting it off from 4-2, and then pauses, at this point, he seems to remember or create the goal of getting the 2-3 subunit which was the stepping stone to success in the previous problem. He then reconnects 1 with 4-2 and moves all the carriages to B. The order is now 1-4-2-3 which is the same as the antepenultimate state of the previous problem, and he proceeds to solve the problem in the same way.

Martin's performance on the other problems is similar. The extra carriages do not pose much of a problem. His general approach seems to be to divide up the train, not necessarily in the most efficient way, and to re-arrange them until subcomponents appear, and the solution becomes obvious. He does not undo moves he has previously made, and he does not produce many redundant moves. He seems to set as sub-goals, the positively evaluated states from previous problems (as in problem 3-1-4-2 above). In all the 5- carriage problems, for example, he creates the state 5-2 or 5-3 on track B, at the beginning of the problem, although this is not actually a particularly helpful state it seems to have been a subgoal. However, all the solutions emerge initially through *step-by-step* planning, looking for the opportunities which the current state affords, and later on with a *short-range* plan towards the solution. These plans being typically 5 moves long, equivalent to a complete solution to a three carriage problem.



## 5.4 Adam (9:2)

Adam (9:2) does not have a train set, although he reported that his brother does. He thus has some exposure to and familiarity with trains, although how much and with which type of train is not clear.

Adam made a shaky start, but seemed to be clarifying the relevant issues, and analysing the problem. He progressed from apparently having problems with the three carriage problems, to succeeding easily on the four and five carriage problems. The improvement was quite dramatic.

The constraints of the problem were not transparent for Adam, in the way that they were for Martin. They had to be discovered, and this was what he was doing in the early tasks. Adam asks appropriate questions, and is ultimately able to encode the answers in a useful way (e.g. that he can't turn the carriages round), so that he does not continually repeat the same errors in later tasks. At the end of the 'learning period' Adam can focus on the relevant issues, and thus concentrate on planning effectively. There is a dramatic improvement, when he is presented with the 4th task. He does not ask any more clarifying questions, and does not 'look back' in terms of performance, despite the increased problem difficulty. Adam's planning is at its best on the more complex problems. It is *short-range* at its best, and so is similar to Martin's performance on the more complex problems

### 5.4.1 Problem 1-3-2

For the problem 1-3-2 Adam's first move is to split the carriages between carriages 1 and 3, leaving 3-2 on track E, and moving 1 to track B (via F). He deposits carriage 1 and move the engine down track G to the E/G/C junction

*Adam: "Damn, I can't turn it round here, can I?"*

*Expt.: "No, the engine's facing the wrong way isn't it."*

He then moves the engine back onto track A (via G), pauses, taking his hand off the engine, then moves it back to the E/G/C junction,

*Adam: "Still is facing the wrong way"*

He then repeats his move back to track A and pauses again with his hand off the engine. He then moves back to track E to join the engine up with carriage 3 and 2. He pauses slightly, with his hand hovering above the carriages as if considering splitting carriage 3 and 2.

*Adam: "Can you have it one, two, three ?"[indicating the carriage in the reverse of the target order]*

*Expt.: "No, the one needs to be next to the engine"*

He splits off carriage 3 and takes it to track A (after some fiddling around trying to get the points right). He then pauses, taking his hand off the train, then goes to separate the engine from carriage 3:

*Adam: "Oh, no"*

He seems to realise that this would block in carriage 3, and he instead moves it to track G . Here he splits off carriage 3 and attempts to leave it.

*Expt.: "I'm sorry I forgot to tell you, you can't leave the train on the curved bit of the track."*

*Adam: "Can't I?"*

*Expt.:* "No."

*Adam:* "Oh, right."

*Expt.:* "You can leave it on any of the straight bits, but not on the curves."

Rejoins carriage 3 to the engine and moves it to track C

*Adam:* "Can I leave it there?"

*Expt.:* "Yes, that would be fine."

Adam splits off carriage 3 leaving it on C. He then quickly moves the engine back round to track E (via G and F) and joins up with carriage 2. Carriage 2 is then moved back to the junction of E/F/D where he pauses. It is then moved with apparent forethought to track A, as some fiddling with the points was required to achieve that goal. He splits off 2 from the engine then utters.

*Adam:* "Oh no"

Immediately realising he has made the same mistake again: the engine is blocked in by the carriage. He then backs the train off track A and incidentally onto track B. While he is concerned with the position of the front of the engine, carriage 2 accidentally joins up with 1. Having solved the front end problem, his hands automatically move to rectify this unintentional coupling, but after pausing he decides against splitting them up. Presumably he recognises the '1-2' sequence, but does not realise that it is not useful because it is reversed. He moves the engine, with carriage 2 and 1 to track D (via F).

*Adam:* "This is impossible!"

He backs onto track E, pauses, moves 2-1 back to C and joins it up to 3, without any conviction. Not with any particular plan, but because his (*step-by-step*) manoeuvring now suggests this option. Having done this he considers his possibilities, and splits the train up, leaving carriage 2 with the engine and leaving carriages 1 and 3 attached together.

*Adam:* "Get off! Can I split them two up ." [indicating 1-3]

*Expt.:* "Yeah."

He then splits up carriages 1 and 3 and leaves them both on track C. He then moves carriage 2 up to the F/G/A/B junction where he has problems with the points. There are two sets of points here, and he is manipulating the wrong set. The experimenter and Adam then have a conversation, during which she explains how they operate. During this conversation he seems to change his mind about where he was going with carriage 2, from track A to track F. It is impossible to tell whether he thought better of the proposed move, remembering that it led nowhere or whether his behaviour was influenced by the points incidentally ending up in the correct configuration for moving round the curve. The latter is hypothesized, but in either case, by the time he had reached the F/D/E junction he had slowed right down and was considering the options. He slowly backed onto track E, then split off carriage 2. From here he could see that he could then pick up carriage 1 and bring it back to link up to carriage 2. This sequence: pick up carriage 1 from track C (via F and G); move carriage 1 back to track E (via G and F) to link up with carriage 2) was performed quickly and smoothly. Adam then splits off the carriages 1-2 from the engine.

*Adam: "Well, that wasn't exactly the quickest way!"*

This comment seems to imply that at this point he had a complete solution plan in mind. In fact, the carriages are aligned in sequence along the bottom tracks with carriage 3 on track C and carriages 1-2 on track E. All that is required is for him to reverse back to track C. However, he seems to misconceive it as a problem of needing the engine to move carriage 3. He had already split the engine off from carriages 1-2, before he made his last statement, indicating that the simple reversing movement was not being considered. He seems to be conceiving of the engine simply as a tool for moving carriages rather than also as part of the problem. When his consideration is turned to carriage 3 he feels he needs to use the engine to pick it up. In any case, he leaves 1-2 on track E and moves the engine quickly to track C (riding roughshod over a problem with the points), he pauses on track C and does not immediately join the engine to carriage 3.

*Adam: "I've got a problem now!"*

He moves carriage 3 slowly onto track E

*Adam: "I can't get around there. [track E] I think I'll go up here. [G]"*

This comment refers to the idea of reversing the engine and carriage 3 onto track E, thus leaving carriage 3 behind the 2. The structure of the problem means that the engine can only go forward onto E from track C, with the engine between the 2 and the 3. He quickly realises this and takes the only alternative move onto track G. He pauses at the end of track G, to consider his options. He then seems to see the whole solution and moves quickly to leave carriage 3 on track B, and to collect

carriages 1-2. He pauses briefly to double check after he has collected 1-2, but the performance is otherwise a continuous movement.

#### 5.4.2 Problem 2-1-3

The second problem for Adam was 2-1-3. He begins by making the redundant move to B, and then stops, and stands back from the train.

*Adam:* "Can I drop all of them off?"

*Expt.:* "Yes."

He then immediately, decisively, and with a flourishing hand movement splits the train leaving carriages 1-3 on B and moves 2 back to track E. This manoeuvre was executed quickly indicating that his question actually related to whether the engine could move on its own, rather than the apparent question of leaving all the carriages in a single block. This indicates he was anticipating two moves ahead. However, he pauses on track E, if he had more of the plan in advance, then he is double checking it. He then splits the engine from 2 and quickly moves back to collect carriage 1 from the 1-3 grouping on track B. (Interestingly, he had not split up the 1-3 in advance as he had done on the previous task - but could consider them separately whilst joined together). He then moves fluently back to track E to join the 1 with the 2, and then immediately splits the engine off from the 1-2. He then pauses. It is possible that his immediate response is to collect the 3, according to his perception that to move things you need the engine. This approach had led him astray in the previous task. He rejoins the engine with 1-2, makes a small movement of the train on track E and pauses again. He then moves 1-2 round to track B, slowly at first then accelerating (perhaps when the orientation of the trains was clearer, and the end state anticipated) to link up with carriage 3 and immediately

removes his hands from the train indicating that he has completed the task. He had completed this trial efficiently in the minimum number of moves. Although the pattern and length of the pauses clearly indicates that he had not anticipated the complete move sequence in advance.

#### **5.4.3 Problem: 3-2-1**

Adam again begins by making a redundant move of the complete train to track B. He seems to begin by moving, and reflecting as he does so. As he reaches track B he pauses briefly

*Adam: "Not so easy!"*

He tries to move forward onto A, but the points are in the wrong position.

*Adam: "I've got to change these little thingies."*

He then changes the points at F/A and moves the train forwards onto track A changes the points at G/B and moves back along track G to track C. Both points changes are made with ease and the movement of train and points is smooth and co-ordinated in marked contrast to his previous attempts.

He separates 3-2-1 between carriages 2 and 1, but they immediately accidentally rejoin themselves (the couplings are magnetic). He perhaps wanted to leave carriages 1 and 2 as separate items on the track. However, when they rejoined he just continued executing his plan and moved on to split the train between carriages 3 and 2. The separation of 1 and 2 was obviously not crucial, as he does not rectify the physical rejoining. Perhaps the act of splitting them initially was sufficient to

represent them as separate. Or perhaps he was just exploring the problem at this stage, rather than following a plan.

*Adam: "Stay there!"*

Adam moves 3 to junction F/G/A/B and pauses, then moves forward onto the redundant track A, and goes to separate the carriage from the engine by placing his hands on it, but then does not do so. He realises (at an earlier stage than in the first problem, that this is a bad move). He then moves the train round to track D (via F), again negotiating the point changes efficiently. He then separates the engine and 3 on D, he realises that this also is a bad move and rejoins them. He moves hesitatingly onto G, back to track E and almost back to C. He seems to be looking for somewhere to leave 3. He then moves carriage 3 forward nearer to the centre of track E and splits it off. He then reverses round to track C and picks up both carriages 2 and 1. He doesn't see that he could build up from 3 if he just took carriage 2. Perhaps this is because the reversed sequencing of carriages 1 and 2 is not appreciated, the visual ordering across the bottom section of the track would have been 3 engine 2 1 (i.e. the goal ordering but in reversed sequence).

Adam brings 2-1 back round to track D, and pauses taking his hands off the train. The ordering is perhaps not what he had anticipated and hoped for. He then backs onto track E pauses for a long time, moves forward onto D again, puts his hands on the carriages as if to split off carriage 1, but then doesn't (presumably recognising that this will not achieve anything before the move is completed). He then moves back onto track E and pauses. He puts his hands on the train as if to split off carriage 1 alone, but both carriages 2 and 1 are detached. He does not move to rectify this. He seems to be more concerned with a goal of



getting carriage 3 from the other side. He moves the engine quickly round (via F and G) to track C where he pauses, and moves slowly onto track E, as if to confirm that the engine is facing the wrong way round. He mutters

*Adam*     *'Bah!'*

Adam reverses back round to the C/G junction end of track E pausing briefly on track C and again on track F. He then returns to the D/F junction end of track E and connects 2-1 up with carriage 3 and takes the whole train (2-1-3) to track B. He pauses, and then splits off carriage 3. He then moves 2-1 swiftly to track E. He then places his hands on the engine and 1, and the train splits between the engine and carriages 2-1 (perhaps not what he intended). He moves the engine forward slightly as if considering this possibility (he had previously 'gone with flow') for previous chance splits. Here, he has a definite idea and pursues his goal. He rejoins the engine to carriages 2-1 and splits off the 1 alone.

He moves carriage 2 round to track C (via F and G). He may have been trying to reverse the sequence of 1 and 2, by depositing carriage 2 behind carriage 1 on track E. Once again he finds that this is not possible because the engine is in between them. On this occasion he does not need to complete the move onto track E to recognise the error. He retraces his steps, moving slowly back up track G, pausing halfway and looking at the other carriages, then quickly moving to the F/G junction

*Adam:*     *"Can I leave one there?"*     *[indicates junction F/G].*

*Expt.:*     *"No. On one of the tracks."*

This choice of location may have been influenced by the fact that it would have left the 2 on the direct path between 1 and 3, and thus in order. However, this being disallowed, he then moves forward onto track A, and pauses considering splitting off carriage 2. Then, without taking his hands from the carriage and the engine he reverses quickly onto B (riding roughshod over the points), joins carriage 2 up with carriage 3 (2-3). He splits off the engine and moves it round to track E and picks up carriage 1. As he is moving the engine and carriage 1 (via F) to track B he says:

*Adam: I've got it now!*

Adam then moves carriage 1 to track B to join up with carriages 2 and 3.

On this problem he seems to have identified the possibility of building up the solution from the end of the sequence, i.e. carriage 3. From this point onwards he uses this strategy to successfully solve all the further problems. As a result he solves them without producing redundant moves (apart from the initial move of the complete train). During these three solution attempts he has clarified the problem space. He has had to overcome the conceptual problem of operations of the points. He has had to identify which of the tracks it is possible to leave the carriages on, and to limit consideration to these. He has had to appreciate the orientation of the train following his moves. Adam has a problem with the left-to-right restrictions on the ordering of the carriages. It is only possible to reverse onto the tracks, so it is not possible to add carriages to the end of a constructed sequence, unless that sequence was attached to the engine. Coupled to this was the inclusion of the engine as part of the problem, not just as a tool to move

the carriages with. The engine itself could form an obstruction. The engine also had to be considered in the sequence, there was a difference between the 1-2-3 and reversed 3-2-1 orderings. This constraint had to be understood in relation to the sub-components as well. Before these points were established, Adam seemed to be unable to plan effectively as he could not predict the outcome of his moves, he anticipated wrongly.

Adam's initial problems are the process by which he establishes the problem space. These things were just automatic for Martin, part of his understanding of train sets. Adam, in contrast, had to discover them and even to repeat misconceptions, before he achieved Martin's level of planning performance. Adam comes to understand the problem - to represent the important constraints in concise ways, so that his other knowledge (from number sequencing, for example) can be applied. He is not acquiring task specific strategies, he is encoding the problem.

## 5.5 Adults

None of the children appeared to consider alternative plans, so there was no evidence of Isaev's *theoretical* level. Although this may be a feature of the problem format (i.e. manual rather than written). If any of the subjects were to exhibit planning at a *theoretical* level it would be the adults. The adults tested were either academic staff or doctoral students all with considerable mathematical or programming experience. It could be assumed, therefore, that they were all competent planners, experienced in manipulating abstract problems. On Isaev's account, such subjects could be expected to operate at the *theoretical* level: producing optimal solutions and where possible exhibiting the complete pre-planning of entire solutions, comparing options before choosing and executing the optimal solution.

The three carriage problems were trivial to the adult subjects. Indeed they worried that they were missing some trick. The limited number of carriages allowed subjects to consider alternative options. The optimal move sequences were between three and five moves. However, once they had envisaged a non-redundant move sequence, there seemed to be no point in considering other possibilities. They did not feel it necessary to compare alternatives to evaluate their proposed solution. It seems unlikely that these subjects *could* not perform at this level, certainly given the problem as a paper and pencil task. However, it is interesting to discuss their behaviour given that they *did not* spontaneously do this. On the 3-carriage tasks, it was possible to generate the complete solution in advance, and to keep it in memory. This provided an overview of the problem, and this understanding of the inter-relationships meant that they generated optimal solutions and did not need to compare them with any other solutions. One subject, M.R. suggested that his performance would benefit from using a pencil and paper, but, these having been supplied, he did not use them. There is quite an amount of effort involved in generating all the alternative move sequences, and there was no strong motivation for the subjects to do this.

There are certain problems which emerged from the children's behaviour that are unproblematic for the adults. The constraints of the task are unremarkable for them, and the interface is (relatively) transparent. For example, the adults could see which tracks were possible locations, knew how to work the points, realised that carriages could only be left if the engine could back onto the tracks. These elements do not even get raised in the protocols - they are not consciously perceived as part of the problem. They are merely background knowledge.

The adult subjects were all satisfied with a non-redundant performance, and believed that they had succeeded (clearly having little insight in to the problem space). They did not consider more than one alternative to any problem, and for the 4- and 5-carriage problems, they certainly did not work the plan out in enough detail to compare solution lengths. It would be impossible to mentally consider all the possible solutions with the four and five carriage task, as the problem spaces reach unmanageable proportions.

Instead, over the course of the trials, the adults seemed to create, a strategy (and a representation of the problem) which allowed them to consistently produce a non-redundant (but not always optimal) solution strategy. In their performance on the five carriage problems (which all had an optimal solution of 7 moves) there was clear evidence of improvement, and the honing of strategies. Subject PG, progressed from 10, to 9 to 8 moves; Subject MK progressed from 11, to 8 to 7 moves, Subject MR, progressed from 8 to 7. Subject AD produced optimal solutions to all of the 5-carriage problems, (apart from a redundant first move, in all cases, moving the complete train to track C, due to her not categorising track E as a possible location)

All the subjects produced their last solution by relying on a type of means ends analysis, which worked well because there were no hidden complexities in the task. This strategy led to the adults, invariably, producing a non-redundant move sequence, but not necessarily producing the shortest move sequence. The complete problem spaces for the five carriage problems, with the engine, 5-carriages and 3 locations is large (8,640 states), and there are a large number of non-redundant, reasonable move sequences. Even the much simpler 3 carriage, 3 location task has 432 states. However, the extra carriages

increase the state space significantly, the fourth carriage multiplies the state space by 4 (to 1,728 states) the 4th and 5th carriages by 20 (to 8640 states).

There was some kind of progression in adult performance. In the three carriage task, they could anticipate the full progress of the task, and compare options without losing the overview. As the number of carriages increased they became unable to do this. They then adopted a strategy, for splitting the task into subgoals, and monitored this for redundancy, but they did not produce the optimal solutions, due to capacity limitations. They honed their task specific strategies over the course of the experiment and improved their performance.

## **5.6 Subject AD**

The case of AD will be taken in detail as she provided the best performance of all the adult subjects. Like the other adult subjects her performance does not reflect a *theoretical* approach even to the three carriage problems. However, AD was the only adult who produced optimal move sequences for all the 5-carriage problems. The train seemed largely irrelevant to AD who treated the problem as a problem of dealing with an abstract number sequence.

### **5.6.1 Three carriage problems**

#### **Problem 1-3-2**

This problem seems trivial for AD, and at various points she is looking for the trick! She immediately analyses the problem as one of removing the 3 from between the 1 and 2 which are already in sequence. There are only two legitimate ways to achieve the sub-goal 'dump 3', and they only differ by which track is used as the dumping

ground. AD chooses track C because the final manoeuvre then just involves (elegantly) backing them all together.

AD does not consider any alternatives because, having defined the problem as 'remove 3' the solution is obvious. She generates the entire sequence in advance, and there is no redundancy, so it is just executed. There are slight problems with the magnets attaching the carriages, but these are easily rectified. She can see, without overt analysis, which tracks are potential dumping grounds without ever having to consider that issue.

### **Problem 3-2-1**

On this problem AD generates a non-redundant move sequence, however it was not the shortest possible sequence. One step would have been saved by using a 'build up from 3 strategy'.

For this problem she begins by transferring a sub-goal from the previous example, indicating that she perceives that the tasks have an underlying similarity which might be useful. However, she does not prioritise this sub-goal. As she follows up her first, 'split and reconstruct' approach, it occurs to her that the obvious solution is to simply reverse the complete sequence, by placing the engine at the other end. She double checks that there is no way she is allowed to do this with the set up provided.

She then returns to her previous plan. She produces the 'towers of Hanoi' analogy which is actually misleading in this context, as the same restrictions do not apply. This may, however, explain her prioritising moving 1 (the smallest ring?) before moving 3 (the largest ring).

At one point she has a significant interruption to the execution of her plan, when she derails the train. At this point, her attention is

switched to the problem of physically locating the train, and she loses track of her goal. She then has to re-consider the state of the problem and reconstruct the sub-goal before she can continue.

### **Problem 2-1-3**

AD initially represents this problem as one of swapping 1 and 2 around, having left the 3 somewhere. She does consider an alternative first move, but she quickly rejects it. It is not clear on what basis this move is rejected, as both of these first moves could lead to optimal move sequence. It seems that it is just not consistent with the initial characterisation of the problem. Having fixed on the first move, the sequence is again generated in advance, no problems are encountered so it is then executed. It was, in this case, an optimal move sequence

### **5.6.2 Four carriage problems**

Performance of each of the four carriage problems was similar, a single example is provided to avoid repetition.

### **Problem 2-1-4-3**

On this problem AD does not generate the complete sequence in advance, let alone compare alternative sequences. Again she is using a global analysis of the problem to generate a single move sequence which is then evaluated. In this case the initial set up is analysed in terms of the two groupings of 2-1 and 4-3. Initially, AD wants to split the train into these two halves and to deal with them separately. However, she quickly rejects that first step, presumably because she realises that keeping the pairings together would not be an efficient first move. Instead she recharacterises the problem as one of breaking everything up. She still considers the two swops as separate problems, and pursues the 4-3 swop first. Having visualised these on separate



tracks she realises that if she can then split the 2-1 pairing in such a way that the 2 is left with the 3, that this would minimise the moves. This is left as a general sub-goal, without an actual plan to achieve it being generated in advance. She then starts to execute the initial stages of the plan. Having split off the 3 and moving towards leaving the 4, she generates the actual move which will allow her to link up 2 and 3. This involves leaving 1 and 4 rather than just leaving 4 on its own. From this point the rest of the solution is obvious.

### **5.6.3. Five carriage problems**

From her protocol it can be seen that subject AD started with a tentative strategy of ensuring that the number 5 carriage was at the back of a track, to avoid smaller numbers getting trapped behind it. (Isaev identifies this movement of the final carriage to the back of a track as the first step to producing the optimal solution path). This strategy is then adopted this as a firm first step in solving problems. She considered alternative first moves for the first of the three problems, and began on a step by step basis. The latter plan only considered a single option, and the plan was worked out in full before execution. However, alternative plans were not considered.

#### **Problem 2-5-4-1-3**

Subject AD initially characterises the problem as one of getting 4 and 5 at the ends of each track. However, by mentally executing the first two steps she realises that this is not possible (on the two tracks which she restricts herself to). She therefore drops consideration of getting 4 at the back of a track and executes the move to get 5 at the back of the track. At this point, she sees that she can then place 4 next to 5 in a straightforward fashion. Having executed this, she then re-evaluates

the remaining problem. She is left with a 3 carriage problem which is trivial for her.

It can be seen that AD considers alternative first moves, but having decided on the first move she then plans in a *step-by-step* fashion. When she has executed the first step, she can then see what the second step should be. Having executed that she is left with a much smaller problem. At no point does she seem to consider alternative move sequences.

#### **Problem 5-3-1-4-2**

For this problem AD begins with the comment "This time it seems slightly clearer that what I need to do is deposit the 5 somewhere, because its at totally the wrong end". She looks three moves ahead, to building up the sub-component '4-5' on track B. She starts to execute this move sequence, but as she goes to pick up carriage 4 she realises (looking a further two moves ahead) that this will mean that carriage 2 will end up behind carriage 3. She considers, but decides to press on. As she leaves carriage 4, she can then see that the perceived problem is not crucial. Carriage 3 can remain attached to the engine, enabling 1 to be left with 2, and 3 to be left with the 4-5 sequence. The rest of the solution is then obvious.

#### **Problem 3-1-5-2-4**

In this problem, subject AD tests out her strategy of build up 4-5, and then solve the 1-2-3 problem, and seems to create a complete, non-redundant solution in advance. She hesitates at the end, apparently because she has generated the complete sequence, but is not holding the complete solution in her head. She has used her strategy to mentally

execute a series of steps which she believes form a non-redundant path to the solution. No alternatives are considered.

When it comes to executing the solution, her performance differs slightly from the plan. It does not generate any extra steps but the presence of the 1-2 sub-component, seems to prioritise creating the 1-2-3 subcomponent, over the 4-5 subcomponent in the mental plan. This influence of 'visual saliency' is a characteristic of *step-by-step* planning, although in this case it is not leading the planner astray in any way.

In the course of the trials AD seems to be evaluating and finally fixing on strategies for the problem. The strategies she selects initially are good ones, and, as they are evaluated positively, no other ones are considered (e.g. build up from 1). AD generates optimal solutions to the 5-carriage problems, but she does not do this by adopting a *theoretical* standpoint. She begins with a *step-by-step* approach and, when the problem is reduced to a manageable size, she uses a *short range* planning approach. As she becomes surer of her two strategies (split into sub-problems and build-up from the end), she becomes able to generate the sequence of moves in advance, but was not able to hold onto and execute the sequence from memory. She had to re-generate them using the same strategies whilst executing the task.

## 6. Conclusion

There was evidence of the *manipulative*, *step-by-step*, and *short-range* approaches described by Isaev (1985) and Magkaev (1977), although these did not characterise the behaviour of individual children. Their occurrence was dependent on the interaction between the child and the particular task or stage of the task. The *theoretical* style was not observed, the main reason being that in this experiment the more

complex tasks which could stimulate theoretical behaviour were presented as practical exercises rather than as pencil and paper tasks (which was the case in Isaev's task).

It seems highly unlikely that the adults tested in this study could *not* have adopted a *theoretical* approach. The adults would almost certainly have been able to systematically generate the entire problem space if an external memory (pen and paper) and enough time was provided (along with sufficient inducements to pursue the problem to these lengths). It is interesting that the subjects did not feel the need to do this to succeed on the problem. One subject M.R. suggested using a pen and paper, but when one was provided, he did not use them.

It was difficult to categorise the behaviour of the majority of child subjects who did not provide any protocol data. This aspect would have to be overcome in some way in a future experiment (see chapter 10). However, the *short-range* and *step-by-step* planning behaviours which were observed were not directly age-related in this sample, as the comparison between Martin (6:6) and Adam (9:2) indicates.

The most insight has been gained from the behaviour of the adults, who were able to provide protocols. Their behaviour indicates that as the task demands increase, performance decreases in terms of Isaev's developmental levels. This is important in any account which argues that cognitive development is knowledge development (see chapter 8). Performance must decrement in a similar fashion (although at different points). If the higher cognitive processes involved in planning do not develop, then performance on a planning task should break down in the same way regardless of age, although the breakdown will occur at different points, for adults and children of different ages. Welsh (1991) in her study of a problem solving task (the towers of Hanoi), noted,

with surprise, that this was indeed the case with her subjects. Older children made the same errors as younger children when faced with more complex problems, which exceeded their processing capacity.

## 7. Planning and problem solving

Planning and problem solving could be considered to be the ends of a continuum, with Isaev's levels of planning lying between them. Wheatley (1984) has defined problem solving as "what you do when you don't know what to do." Planning could be taken to describe what you do once you *do* know what to do. Although, between these extremes there are various levels of 'knowing what to do'.

With very complex problems people may not know where to begin. However, this is rarely the case as there are many general problem solving heuristics available. In clearly defined domains (such as the train task) a lack of understanding of *how* to achieve the goal will not preclude moving appropriately, without necessarily moving strategically towards the goal. Manipulating the problem may be a way of generating new states from which the solution may become apparent, or the constraints of the problem become clearer. Isaev's *manipulative* approach does not really constitute planning, but may rather reflect the most general of problem solving heuristics applied to an ill-understood problem. Isaev's train task permits planning, once the various domain restrictions have been understood. But, for the youngest children (e.g. Ben 5:2), it is a problem solving task comparable to the Chinese Ring task (Kotovskiy and Simon 1990) where even the definition of what constitutes a move is not clear.

A *short-range* plan requires a definite goal (although this may be a sub-goal of the complete problem). A sequence of steps are then

explicitly generated to achieve this goal. It requires an ability to recognise 'solvable' states, or promising subcomponents in relation to the goal, i.e. perceiving patterns to motivate the plan. The *step by step* approach is intermediate between these two approaches. A general strategy (e.g. build up from 5) may guide an initial step, but no definite path towards the goal or sub-goal is being followed. Small steps are taken, until the pattern of the problem becomes clearer, and a path to the goal, or an obvious constituent (sub-goal) becomes apparent. At this point a *short-range* plan can be generated to achieve the goal. The *theoretical* approach requires an overview of the complete solution which would allow for the comparison and evaluation of possible solutions. On the train task, it seems that the memory load was such that a theoretical approach required an external memory (perhaps because on top of generating a solution sequence the number of moves also had to be counted. These activities could not be carried out simultaneously).

The continuum between planning and problem solving is illustrated by Bodner and McMillen's (1986) distinction between *problems* and *exercises* in relation to answering chemistry problems. According to this definition, if you know what to do when you read a question, it's an *exercise*, not a *problem*. The status of a given question as a *problem* is not an intrinsic attribute of the question itself. The problem is in the eye of the beholder. It is a feature of the individual's interpretation of the question, i.e. of their encoding and representation. The line between *problems* and *exercises* in any domain will be defined by the individual's level of expertise.

Students can learn a set of algorithms for solving chemistry (or any other problems), but these are of no use unless the student is able to

identify the relevant question. Chi, Glaser and Rees (1982) have demonstrated in the physics domain that experts and novices categorise mechanics problems in different ways. Novices concentrate on the surface features, e.g. problems which involve an inclined plane, whereas experts analyse them directly in terms of their solutions e.g. those solvable with Newton's laws. Experts' additional knowledge has led to a new way of *perceiving* physics problems. This encoding step is crucial to problem representation. In the same way that novice physicists were misled by the surface features of the problems, so Ben's (5:2) understanding of the train task caused him to represent the problem in terms of what he did understand, i.e. in terms of a 'play schema'.

Larkin, McDermott, Simon and Simon (1980) have looked in detail at the problem solving processes of novices and experts. They argued that novices used means-ends analysis in an erratic way. They seem to have been using a general problem solving strategy, rather than a specific one, and using a *step-by-step* approach. In contrast, experts perceived the solution directly and only applied the appropriate equations. They are encoding the problem in such a way that the solution is obvious. With sufficient domain knowledge, the solution becomes perceptual. In the train task, this immediate perception of the solution to 3-carriage problems obviated the need to consider alternative move sequences by competent subjects.

The importance of encoding and representation is evident in the lack of transfer of solution algorithms (Bodner and McMillen 1986) or problem solutions (Gick and Holyoak 1980; 1983) between situations. Providing isolated strategies does not help subjects to recognise appropriate situations for applying the algorithms. The basis for

transfer is understanding, which depends on having an elaborated knowledge base, and being able to take an overview (this will be developed in chapter 9).

Problem representations allows for different level of planning. Ben's representation of the problem allowed him to achieve a direct solution to the problem (picking the carriages up), but did not allow him to succeed on the task as defined by the experiment. Adam's initial inaccurate representation allowed him to manipulate the train, however, with increased understanding of the constraints he was able to *re-represent* the problem in a solvable way.

## 7.1 Interacting knowledge

There were various types of knowledge necessary to perform the train task successfully, and which would lead to different representations of the problem. Ben (5:2) brought the most basic of these into focus, he neither understood the problem nor the social situation. At a higher level, Adam (9:2) had problems with the 'interface', the physical train set. There were motor problems with the points, and with the magnetic couplings re-attaching. When attention had to be concentrated at these lower levels of the task, higher levels plans are forgotten. Both Adam and AD lost track of their 'plan' when the 'interface' got in the way: for example AD had to re-create a goal after a de-railing problem. The train task requires to subject to limit their attention to the tracks which are relevant to the task. A lack of appreciation of the relationship between the track sections and the orientation of the train, caused problems for Adam, but not for the younger Martin. Experience of trains meant that this aspect of the task was entirely transparent for Martin (and the adults). These constraints were literally unremarkable for them. In contrast, Adam had considerable problems: he is initially unable to



understand the relationship, which meant that anticipated moves were mis-predicted. However, he quickly assimilated these constraints, and was then, able to focus on the underlying problem and improve his performance. In contrast, Martin (6:6), was able to move the train smoothly and did not experience any interruptions due to the interface, he was directly engaging the problem<sup>6</sup>. A succession of such interface problems would inevitably lead to a *step-by-step* performance, because any *short-range* plans would be prematurely lost.

The adults found the interface transparent, but perhaps more than this, they classed it as largely irrelevant. They focussed on dealing with the abstract number sequences, and generated higher level characterisations of the problem in terms of crossed sequences and interleaved numbers, for example. Chi and Ceci (1987) have argued that it cannot be assumed that children's knowledge of number is the same as adults', even in relation to basic number sequences. In terms of the initial representation of the problem, this kind of knowledge differential seems to be implicated in this experiment. This will, in turn affect the strategies adopted, and the salience of sub-components.

When the problem space is understood, the 3-carriage problems are almost perceptual, they are not really a problem because the solutions are obvious from understanding the problem. The four and five carriage problems become more complex, and there is change of approach. The strategy is then such that the problem is reduced to one where the solution becomes, again, obvious.

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<sup>6</sup> This is similar to the concern for 'direct manipulation' interfaces in the human computer interaction literature (Hutchins, Hollan, & Norman 1986).

## 7.2 Strategy creation

The behaviour of subjects indicated that they were developing specific strategies as they interacted with the task. As subject AD progressed on the task, she adopted certain heuristics more firmly. Along with other subjects she remembered significant states from previous problems, and began using these states as subgoals. As these subgoals became firmer, less effort was required to analyse the problem, and the further the subject could look ahead. Experience allowed exploration of the problem space, and the identification of strategic subgoals. This drive to understand the problem continued despite success, to ultimately achieve the smoothest possible performance with the minimum of monitoring. This is comparable to Agre and Shrager's (1990) study of photocopying which indicated that the 'practice' effect is not mere 'speeding up', but the refinement of strategies.

## 7.3 Problem representation

Isaev's concern with 'analysis' has been interpreted as 'problem representation'. In the problem solving literature there is evidence of the importance of encoding. Success in planning and problem-solving tasks crucially depends on how the child or adult represents the problem to themselves. Amarel (1966 cited in Simon 1981) states that problem solving is just a matter of finding a representation in which the solution is obvious, i.e. it is the representation which turns a *problem* into an *exercise*. It has been established that the content of cover stories make a great difference to the process of problem representation. Those that are consistent with general knowledge are easier for subjects than those that do not fit. Wason and Johnson-Laird (1977) have shown this with the card-turning reasoning task, and Kotovsky, Hayes and Simon 1985 with various isomorphs of the tower

of Hanoi. If less capacity is used on holding the problem statement in working memory, then more capacity is available for solving it. The logical limit may occur in children (and adults on some problems) where all the capacity is required for the former, and therefore no solution is possible (or manipulative behaviour results). This indicates that whilst there must be absolute capacity limitations, there are also contingent capacity limitations based on the interaction of the problem representation with the absolute capacity limitations.

## 8. Chapter summary

A partial replication of Isaev's planning task was presented, to test the hypothesis that planning development involved the creation of new planning processes. This was proposed as an alternative to a representational redescription approach of knowledge development. Isaev's planning stages were demonstrated: however, rather than indicating an absolute level for an individual, it was argued that it reflected the individuals knowledge level interacting with problem complexity. In adults, the planning mode decreased from *short-range* to *step-by-step* as the state space of the problem increased. Planning never occurred at the *theoretical* level on this task.

Children need to clarify the problem space and to understand the constraints of the task, before they could plan. This supports Isaev's emphasis on the development of problem analysis, although the explanation presented here is one of the development of problem representation interacting with capacity limitations, i.e. it is a knowledge development rather than a process development account. The development of encoding and problem representation is dependent on domain specific background knowledge.

At this stage we have rejected Karmiloff-Smith's specific RR model, but have not rejected the underlying principle of representational redescription. In this chapter and the last, only one complete account of planning development was found , and it has been argued that the apparent process development can be explained in terms of knowledge development. In chapter 8, the knowledge development position will be supported further. In chapter 9, a new account of representational redescription will be proposed. The empirical evidence from this chapter illustrated the need to consider the issues of problem representation, and capacity limitations in developing that model.

## **Chapter 8**

### **Cognitive Development as Knowledge Development**

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#### **Chapter Abstract**

The empirical work presented in chapter 7 indicates that the development of planning ability reflects the development of knowledge rather than the development of any cognitive processes. This chapter presents further supporting evidence for the 'knowledge development' view. It is argued that apparent developmental differences in processes can be explained by differences in knowledge. The apparent development of higher cognitive processes, is a feature of the interaction between the processes and the child's knowledge base (e.g. Chi and Ceci 1987). The correlative evidence of 'early competence' indicates that children do possess higher cognitive processes at an early age, but their performance is limited by their understanding of the relevant knowledge content. The justification of the knowledge development position provides the basis for the re-formulation of representational redescription which is presented in chapter 9.

#### **1. Introduction**

Karmiloff-Smith's Representational Redescription (RR) model (Karmiloff-Smith 1986) was analysed in chapter 5, and some modifications suggested. One of the fundamental changes proposed

was to drop the problematic concept of 'behavioural success'. Karmiloff-Smith limits her explanation of behaviour to development beyond 'behavioural success' and does not relate her model to general theories of cognitive development. In chapter 5 it was argued that whilst it was an important insight that development does not end with successful performance, there needed to be some justification for proposing a different developmental mechanism for the 'post-success' period. No justification has (to date) been found. 'Success' has also been shown to be hard to define in many domains (see chapters 3 and 5). Consequently, it was suggested, in chapter 5, that the concept be dropped. The full implications for the RR model will be elaborated in Chapter 9. In this chapter, the main consequence of the dropped constraint will be pursued: the broadening of the applicability of representational redescription to development in *general*.

As a general developmental model representational redescription becomes a 'knowledge development' theory, involving changes in the structure of knowledge. No additional developmental of cognitive processes are suggested<sup>1</sup>. The qualitatively different knowledge levels in the RR model (Karmiloff-Smith 1986, 1992) might be taken to imply structural changes, but these will be dropped from the reformulated recursive account to be presented in chapter 9. Before presenting the reformulated model of representational redescription, this chapter will argue in general terms that knowledge development is central to cognitive development, along with the correlative argument that cognitive processes do not develop, qualitatively. The latter position is supported by the empirical work on planning presented in chapter 7.

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<sup>1</sup> It is not suggested that Karmiloff-Smith would subscribe to this view of representational redescription, if she were to broaden her conception to form a general developmental mechanism.

This chapter begins with Carey's (1985) question "Are children fundamentally different thinkers and learners than adults?" It will be argued that children are not *fundamentally* different - the apparent differences are attributable to knowledge development - although various suggestions for fundamental differences are considered. In the previous chapters it was argued that knowledge development rather than the development of planning processes was responsible for performance improvements. The corollary of the knowledge development view, is the 'early competence' approach to cognitive processes, which is then presented. Processes reserved (in structural theories) for adults are demonstrated as being available to young children, given the relevant domain knowledge. Knowledge development is obviously not a mere accumulation of knowledge, it involves restructuring. Accounts of the development of the structure of knowledge, with increased quantity are then considered.

## **2. Developmental differences**

A knowledge development account must hold that children do not think in fundamentally different ways than adults. Carey (1985) has concluded that the most important differences between adults and children relate to the accumulation of knowledge.

Carey (1985) identifies five ways in which children could be said to fundamentally differ from adults, these are:

- (1) domain specific knowledge.
- (2) tools of wide application
- (3) metaconceptual knowledge;
- (4) representational format;
- (5) foundational concepts;

These will be considered in the following sections, with the additional category of the development of processing capacity. Carey argues that differences exist in the first three categories, this thesis will argue only for difference in the first two categories.

## 2.1 Quantity of knowledge

It is undisputed that, *ceteris paribus*, younger children know less than older children. They clearly differ in 'domain specific knowledge'. This lack of knowledge has serious ramifications for children's performance in ways that may appear, on first examination, to be unrelated to knowledge.

If 'tools of wide application' are defined as strategies, heuristics and skills, then again children and adults will clearly differ. Language might be considered to be the most general of the tools, the development of language abilities will clearly impinge upon a large number of tasks. However, the differences are not a feature of age *per se*, nor of cognitive structure, they are a difference of knowledge. They do not, therefore, constitute *fundamental* differences.

An increase in general knowledge has a number of implications: children are universal novices, and this will limit the analogies which can be made across domains. Keil (1991) argues that this will give rise to differences in learning in childhood which mean that this will not be comparable to learning in expertise. However, this does not constitute a *fundamental* difference in learning processes nor in organisational structure. Children who are experts in a domain will acquire knowledge, and organise it in the same way as adult experts. They will be able to draw analogies from other knowledge domains, although,



there will clearly be less of these domains available to children than to adults. If the knowledge-related differences were to be factored out, the underlying learning or developmental mechanisms should be the same. The comparison of expert adults and children in terms of their creative processes will prove useful in developing the Recursive Re-Representation (3R's) model in chapter 9.

Differences in quantity of knowledge will also result in (quantitatively) different structures of that knowledge. Carey (1985) argues that children and adults may have different theories as a result. Changes in the organisation of knowledge will be discussed further in section 5, and in chapter 9.

## 2.2 Metaconceptual knowledge

Carey (1985) accepts that there are differences between adults and children in 'metaconceptual knowledge', she argues that children may lack 'metaconceptual knowledge':

"Unlike adults, children cannot think *about* their mental representations and inferential processes"

Carey 1985 (p. 106, emphasis in original).

This is exactly the kind of development that Karmiloff-Smith (e.g. 1992) wanted to explain with her RR model and which, it will be argued, can be explained by the 'Recursive Re-Representation' model to be presented in chapter 9. Both of these representational redescription accounts explain the development of this kind of conceptual overview purely in terms of knowledge development, although acquiring knowledge in the domains of 'mind' and 'thought' will obviously be fundamental to many other domains.

Carey (1985) describes an example of metalinguistic change which, she argues, involves only the acquisition of knowledge (however, she does not feel able to conclude that this explains all metaconceptual change). She cites Piaget's (1929) example of asking preschool children whether the word 'needle' is sharp. The children answer that it is sharp, because they do not focus on the 'word' but only on the referent. Similarly, young children will claim that the word snake is longer than the word caterpillar. However, Carey (1985) does not feel able to conclude that children and adults do not differ 'metaconceptually'. This kind of concession to 'metacognition' is also found in Goswami's (1991) knowledge development approach to analogical reasoning, but, it will be argued below, the concession is unnecessary .

Clearly children lack metaconceptual *knowledge*, relative to adults, just as they lack 'domain specific knowledge', and 'tools of wide application'. However, Carey does not distinguish metaconceptual knowledge from metaconceptual *abilities*. In fact, she seems to use the term metaconceptual development to refer to both. As was argued in chapter 2, following Flavell (1979): (meta)cognitive knowledge does not differ from knowledge in any other domain, and is acquired in exactly the same way. The chronological progression from domain knowledge to (meta)conceptual knowledge is unarguable. The ability to reflect on language must be preceded by the ability to use that language. On this interpretation, adults will obviously have more metaconceptual knowledge than children simply because they have more knowledge than children. However, unless Carey suggests (with Piaget) that the development of a general 'reflective capacity' is responsible, then the differences may be explained by increased domain knowledge.

The preschool child who fails to answer the question about 'words' probably does not have the concept of a 'word' to use in making this judgement. Even if they did have some referent for the word 'word' it would clearly not be the adult version. Young children are adept at making the best sense out of incomplete (to them) communications and their interpretations do make the request sensible. Perhaps they just ignore the word 'word' when it does not find a coherent referent. In the "Is the word needle sharp?" example, the 'correct' interpretation of the sentence is quite complex. Answering 'no' to the question would imply that the word needle is 'not sharp', i.e. it is 'blunt'. A further level of conceptual analysis needs to be involved to answer the question correctly. A linguist might answer that 'sharpness' cannot be attributed to a 'word', and the utterance is thus infelicitous, rather than true or false. Alternatively, a poet might take a metaphorical approach to the word and conclude that the 'ee' in 'needle' did make the word sound quite 'sharp'. These 'meta-meta' conceptual interpretations perhaps more obviously implicate knowledge development, than the first level of metalinguistic knowledge which would be acquired early on in a literate culture.

The implications of acquiring (meta)conceptual knowledge, in any domain will have widespread implications. This is clearly the case in the 'theory of mind' (see chapter 2). However, this does not amount to a fundamental difference in cognitive processes. To pre-empt the Recursive Re-Representation account (chapter 9), knowing about words, rather than just using them will involve a Re-Representation of the knowledge implicit in using words. It forms a new conceptual space, which in structural terms requires the creation of a higher level in the knowledge hierarchy. However, this would not be qualitatively different from earlier or later Re-Representations involved in learning

the meanings of the words, or learning about poetic uses of language. All of these Re-Representations will change how the world is perceived, but they will be a fundamentally a function of increased knowledge, rather than of the development of a 'reflective capacity'.

### **2.3 Foundational concepts**

Carey (1985) cites Piaget's (1929) argument that children differ in the content of foundational concepts, such as 'causation'. However, Carey argues that this proposition reflects an association of the underlying reasoning with the content which is reasoned about. The content of children's theories will change, and this will affect the conclusions drawn. This is a feature of knowledge acquisition and restructuring, and will be discussed further in section 5. Carey cites Bullock, Gelman and Baillargeon's (1982), review which indicates that the same principles of causal explanation are adopted by 3 year olds up to adults, but there are marked differences in the ability to reflect and thus articulate the concept of causation. It is implicit in their reasoning, but has not been explicitly represented.

### **2.4 Representational format**

In the category of 'representational format' Carey (1985) places the stage theories of Piaget, Vygotsky, and Bruner. These theories argue for qualitative changes in domain-general cognitive processes or in representational format during development. This class of structural changes would include Vygotsky's complex to concept shift, and Piaget's development of operational thinking,

This type of global explanation provides a blanket explanation of the differences between adults and children in term of a structural deficit. This, of course is the most fundamental difference possible, entailing

that children could not, in principle, represent or reason in the same ways as adults. Smith, Sera, and Gattuso (1988) have argued that the problem with both Piaget and Vygotsky was the notion of internalising logic: the internalising processes are logical themselves, as they must separate the valid from the invalid.

Mandler (1988) characterises Piaget's account of the development of a symbolic capacity as a long drawn stage of the transformation of sensorimotor information. She dismisses Piaget's idea that concepts can develop out of sensorimotor representations, because the mechanisms of transfer from one system to the other (and particular the intermediate transition states) have not been explained. She argues that the child's accessible knowledge system, with a symbolic representational code, must be present from birth and develop alongside the sensorimotor representational system. Mandler's (1988, 1992) account of conceptual development, is discussed further in chapter 9.

## **2.5 Processing capacity**

A sixth potential difference between adults and children which is not on Carey's (1985) list, is the development of capacity, and/or processing speed. These were perhaps excluded because they are not *fundamental*, qualitative differences. However, such explanations have been suggested (e.g. Case, Kurland & Goldberg 1982; Kail 1986). However, it is possible that capacity does not develop, but just appears to develop on the basis of elaborated knowledge. Chi (1976) has shown that the oft-quoted difference in memory span between adults and children is reduced to insignificance when items are equated for familiarity between the age-groups. In this thesis, it is possible to remain agnostic on the issue of capacity changes, the account does not

stand or fall on the basis of whether memory capacity or processing speed increase with maturation or not (although see Chi and Ceci 1987, for arguments against) .

### **3. Early competence**

The initial moves away from structural views were characterised by experiments which showed 'early competence' (e.g. Donaldson 1978). These experiments took tasks which had been taken to indicate children's inability to sort out a logical problem and showed them to be artefacts of the knowledge required of the task

#### **3.1 Transitive inferences**

One of the logical abilities that Piaget argued was lacking in young children was the ability to make transitive inferences. He argued that young children could not infer 'Sam is taller than Fred' from the premises "Sam is taller than Henry" and "Henry is taller than Fred". However, Bryant and Trabasso (1971) argued that this was an effect of incorrect encoding of the concept 'tall'. Children did not lack the ability to make the appropriate comparison and deduce the conclusion. Tall is not encoded as a comparative attribute, but as a category, thus 'Sam is taller than Fred' is encoded as 'Sam is tall', which does not provide the basis for a transitive inference. Trabasso and Riley (1975) showed that training children on the premises, enabled them to produce transitive inferences.

Smith, Sera and Gattuso (1988) argue that children do not often make transitive inferences in their everyday lives. This is unlikely to be independent of their encoding of relationships. If you don't tend to encode in this way, then such relations will not be apparent. It is a

matter of knowledge that the phrase 'X is taller than Y' implies more than that X is tall - in fact it does not imply that X is 'tall' - it could be said of two midgets. It is a complex understanding and children do not encode relational information, unless it is made explicit.

The general conclusion from these studies indicates the importance of encoding in success on these tasks. We will review the idea of development of encoding with reference to the adult literature.

### **3.2 Metaphor**

Keil (1984) has argued that the development of understanding of metaphors reflects the development of knowledge in a domain, rather than the development of a general reasoning ability. Thus, young children can understand metaphors between vehicles and animals, e.g. "the car is thirsty", but not between eating and reading, e.g. "he gobbled up the book", the latter being interpreted literally. This relationship between knowledge and metaphor continues into adulthood, there is a need to understand the relationships within a semantic field before comparisons can be made between semantic fields. In the terminology of chapter 9, this means that the semantic field must have been 're-represented' to provide a new conceptual space. An adult who does not understand anything about computing will not appreciate computational metaphors about cognition. This would not reflect any general lack of 'metaphorical abilities'.

### **3.3 Chess**

It is difficult to compare the processing capacities of children and adults directly. Obviously, any behaviour is the result of the interaction of both knowledge and processing. There are few domains where the knowledge component is isolated enough for some kind of comparison

to be made. But, one such domain is chess. Chase and Simon (1973) have shown that experienced chess players exhibit superior memory for chess-game positions than novices. However, they clearly demonstrated that this was not due to any superiority in general memory capacity, but just to an ability to 'chunk' the information. The difference has been shown to persist between child-chess experts and adult novices, indicating that it is purely a function of knowledge, not affected by 'developmental level'.

#### **4. Knowledge restructuring during development.**

As knowledge develops, it must be restructured, otherwise experts would take longer to search their memories than novices. In terms of knowledge format in children: the more that is known, the more differentiated the representation of that knowledge becomes. Carey (1988) has shown that conceptual hierarchies have more levels in adults than they do in children.

##### **4.1 The 'characteristic-to-defining' shift**

Keil (1984, 1986), has identified the 'characteristic-to-defining' shift in concept representation. This is a general developmental progression from typical features to clearer definitions of concepts. For example, young children initially rely on typical features, e.g. that Grandmothers have grey hair, rather than the defining features (i.e. parent's mother). Keil and Batterman (cited in Keil 1984, 1986) tested this progression by asking children for judgements of category membership. They presented children with stories in which atypical instances were clearly defined as category members (e.g. for 'uncle': a 2-year-old infant who is your father's brother) and stories where typical examples were



definitionally excluded (e.g. for 'uncle': a man similar to your father who gives you birthday presents, but is not related in any way). Younger children accept typical examples as category members, and reject the atypical ignoring the definitions. Older children, in contrast, give priority to the definitions. The shift from characteristic to defining features occurs at different ages for different domains. It is, thus, a domain specific phase model which Keil (1984) contrasts with Vygotsky's (1962) domain-general stage model of the complex to concept shift.

Keil (1986) argues that this representational shift seems to be related to purely to knowledge development, and may continue into adulthood. Chi, Feltovich and Glaser (1981) have illustrated the characteristic-to-defining shift with adults (although not using that term). They asked physics experts and relative novices (1st year undergraduates in physics) to sort a set of physics problems into categories. The novices sorted on the basis of superficial features, and the experts extracted the essence of the problem, and sorted according to the laws of Physics.

In a training study, Keil (1986) found that acquiring unfamiliar cooking terms (e.g. baste) required a background of other cooking terms. It is only when the child understands what the relevant dimensions are that they can assimilate the definitions.

"What you learn influences or exerts constraints upon what you will learn next, not only in terms of the process of learning itself but in terms of how it comes to be represented. If one has a rich knowledge of cooking terms, for example, then one will have different representations of novel cooking terms than a novice, differences that may be striking and qualitative in nature. These constraints are products of the structure of what is learned, and their restrictiveness and generality depend on the knowledge involved. It is assumed here that the various areas of expertise that exist in our world have many unique structural properties that become all the more pronounced with increasing expertise. Thus, novice-to-expert transitions may frequently represent qualitative shifts in manner of processing and representation."

Keil 1986 (p.156)

It is not clear where the proposed structural and qualitative shifts come from. It is perhaps a feature of knowledge content rather than a qualitative differences in structure.

## **5. Against the knowledge development view.**

Peeverly (1991) has argued that knowledge-based explanations of development do not account for the evidence of domain-independent strategy development. He conflates the idea that knowledge develops, with strategies developing. The same cognitive processes will operate differently over a different knowledge base. However, the acquisition of learned strategies is a matter of knowledge development; domain general strategies may be formed by redescription of domain specific ones.

Peeverly has argued that researchers have been wrong to use single level tasks, as these don't tax the experts, and may be too hard for the

novices. He argues that to look at problem solving processes each should be presented with a task which poses each with equal difficulty for themselves. He argues that for experts physics problems, for example, may just be retrieval, but this is to miss the point. The experts will not have retrieved the exact problem - they are unlikely to store specific examples. The fact that a new example of a familiar problem poses no difficulty is precisely because they have the knowledge stored in such a way as to be able to *encode* a new problem in such a way that the solution is trivial (see chapter 7). They may well use the same domain general processes and strategies in a complex domains - the difference in encoding and performance relating to knowledge.

## 6. Expertise

Adults are novices in some domains, while children are novices in almost all domains, including basic general knowledge (and language). As we have said, the younger the child the less they know. The results above indicate that this lack of knowledge in itself would lead us to predict age related differences in the ability to form problem representations and in performance in most domains.

It is obvious that experts have more knowledge than novices, but their performances show that there is more to it than that. They differ in the way that the knowledge is structured. The domains that have most commonly been studied are chess, mechanics problems in physics and mathematical problem solving (see Chi, Glaser and Rees 1982). Evidence of the different approaches to tasks indicate that (a) novices have different beliefs - 'no motion without a force' rather than 'no acceleration without a force' (Clement 1982 - quoted in Carey 1988). Although Clement's novices has completed a first year undergraduate

course on Newtonian mechanics, they did not have that knowledge integrated in such a way that it could be produced in response to the test question. Naive physics persists - it could be that the breakthrough is in realising that the two systems are separate, and differentiating them. And this may happen when some unifying knowledge allows the Newtonian Physics to form a complete system quite apart from everyday behaviours. The problem is not one of conceptual modification, but ultimately of building a new conceptual system: the initial stages may come by appending the new knowledge to existing structures, but this is decidedly unhelpful.

There is an extensive literature on the problems of getting conceptual change in science. Part of the problem here, is that it is not conceptual change that is required, but the temporary suspension of an 'everyday' conception of the world, and the adoption of a 'scientific' approach. Even graduate scientists can be found to operate with 'everyday' concepts, and this is because they have not dropped their everyday concepts, they have just learnt a separate system which is adopted when appropriate (i.e. in the work context). Those that try to integrate the scientific perception into their everyday life will be lost. It just is not helpful to go about your daily life perceiving the world as though everything was in constant motion, for example. This is equally true for logicians, who leave formal logic behind in everyday reasoning tasks (e.g. Johnson-Laird and Wason's card turning reasoning task (Johnson-Laird 1990)).

## **7. Chapter summary**

The RR model has been criticised in earlier chapters although we have not rejected the basic idea of representational redescription. An

underlying assumption of representational redescription is that cognitive flexibility is the result of the development of knowledge representations, rather than the result of the development of cognitive processes. To continue developing representational redescription into a more general development model it was necessary to justify the idea that cognitive development is knowledge development. The idea that development can be explained purely in terms of increasing knowledge has been suggested by Carey (1985). Chi and Ceci (1987) also stress the importance of knowledge development, arguing that the acquisition and restructuring of content knowledge can provide an explanation of apparent developmental changes in memory.

It has been argued that children are not 'fundamentally different thinkers' from adults. They differ in knowledge, but not in higher cognitive processes. Domain knowledge, strategies, heuristics, and 'metaconceptual knowledge' will differ, and these will cause marked differences in performance. However, the knowledge development approach makes a clear prediction about where to look for development. It is in content and knowledge structure. A representational redescription account of knowledge development will be presented in the next chapter.

## Chapter 9

### **Recursive Re-Representation: towards a new theory of representational redescription and cognitive flexibility**

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#### **Chapter Abstract**

In this chapter a new model of representational redescription is presented, called the Recursive Re-Representation (3R's) model. This model views representational redescription as a creative process, and is based on Boden's (1992) computational analysis of creativity. Recursive Re-Representation creates new levels of knowledge or conceptual spaces, which allow things to be thought which could not have been thought before.

The 3R's model involves the recursive operation of the perceptual analysis process responsible for creating the original representations in infancy (Mandler 1988, 1992). Perceptual analysis, which involves perception, analogical reasoning and evaluation, creates *re-*representations in exactly the same way as it creates initial representations. Re-representation results in increasingly compact representations which allow increased cognitive flexibility in a domain. This is achieved through either the chunking of knowledge within a conceptual space, or the creation of a higher level conceptual spaces, allowing an overview of lower levels and a more dramatic shift in

flexibility. Recursive re-representation results in different level of 'mapping' of domains, in a basically hierarchical fashion.

Cognitive flexibility is attributed to the contents of working memory, the latter being capacity-limited in terms of 'chunks'. Recursive Re-Representation will create different levels of knowledge, or conceptual spaces. These levels of knowledge and awareness are related to the three levels proposed in Activity theory. The developing model of Recursive Re-Representation is briefly related to the BAIRN system, which provides a potential formalism for specifying the model in more detail.

## 1. Introduction

In previous chapters the details of Karmiloff-Smith's (1986) model have been questioned, but the underlying principle of representational redescription remains a plausible developmental mechanism. Following from the rejection of 'behavioural success' in chapter 5, the 3R's model is proposed as a general, recursive, representational-development mechanism. It will be argued that it is a *general* developmental mechanism with wide application, but not that it is necessarily the *only* developmental mechanism.

Representational Redescription (Karmiloff-Smith e.g. 1986, 1992) was initially proposed as an explanation of the development of cognitive flexibility, and this remains a central concern of the 3R's model. Development is explained by representational change, rather than the development of any 'flexible thought processes'. This approach was suggested by the empirical evidence from Isaev's planning task presented in chapter 7. It was argued that planning ability was a function of domain knowledge. The general knowledge development

approach was defended in chapter 8. The 3R's model is purely one of knowledge development, in contrast to Karmiloff-Smith's RR model which also had a structural element. She proposed that knowledge development involved redescription into qualitatively different representational formats which, presumably, do not exist at birth (prior to 'success' in any domain). The 3R's model will drop the structural element (a structural approach is, in any case, hard to pursue with a recursive model). It will maintain Karmiloff-Smith's conception of domain general redescription processes, but with each 'level' of redescription differing in terms of increasing compactness of the representations rather than the format. The compactness is achieved through Re-Representing several chunks of knowledge as a single chunk. Cognitive flexibility is then explained through the liberation of central processing capacity by chunking in a domain. Chunking is an ill-defined process, but Recursive Re-Representation provides one possible explanation of the process of compacting representations.

Karmiloff-Smith's conception of Representational Redescription was of the development from specific representational codes, to more general, more accessible ones. That directional constraint will also be removed from the 3R's model, which will also allow for redescription from general linguistic representations into more specific representational codes. This will explain the development of 'automatic' motor skills from linguistic instructions, and such processes must be included in a general developmental mechanism. This will be possible in the 3R's model because each level of re-representation involves a 're-perception' and re-encoding' and can therefore take any form that an original encoding could take.



Representational redescription generates entirely new representations, as such, it is fundamentally a *creative* process. Boden (1992, 1993) has provided a computational approach to creativity, and her analysis of creative processes will organise much of this chapter. It will be argued that the explanation offered for adult creativity can also contribute to explaining development. The 3R's approach uses Boden's (1992, 1993) concept of the mapping and transforming of conceptual spaces.

The 3R's model is more interactive (influenced by socio-cultural approaches) than the RR model which emphasises endogenous redescription processes. The planning and block balancing experiments (chapters 7 and 4) highlighted the importance of 'encoding' and problem representation: the interaction of top-down and bottom-up information. Mandler's (1988, 1992) idea of 'perceptual analysis' in concept formation which she has applied to development in infancy, provides the basis for a general representational mechanism in the 3R's model. 'Perceptual analysis' will be generalised as a mechanism for creating new representations based on the observation of the individual's behaviour.

The 3R's account will not be developed to the level of specificity of Karmiloff-Smith's (1986) RR model. As such it is decidedly 'soft core' (Klahr 1992). However, it will be related to a rare 'hard core' model of cognitive development: the BAIRN system (Wallace, Klahr, and Bluff (1987). This model, though based on a production system architecture, includes an atypical hierarchical knowledge structure (based around 'nodes'). Crucially, for the 3R's account, development in BAIRN involves the *creation* of new nodes, on the basis of the observation of the *performance* of productions. The 3R's account will not be

developed to the level of describing representations, it focuses instead on the processes involved. As a consequence, this chapter will not argue for or against the psychological validity of either BAIRN'S production system architecture or Mandler's (1992) 'image schemas'.

## **2. Representational redescription as a creative process**

Representational redescription generates entirely new representations for the individual. It is, therefore, a creative process. In the RR model, each new representation contains information which has been extracted from analysing lower level representations and is entirely novel to the subject. In RR theory the new representations were novel both in terms of content and in qualitatively different formats. The representations were redescribed from modality specific representational codes into a domain general accessible format. The 3R's account like the RR model proposes the creation of new representations. However, it drops the limitation of a progression towards a domain-general, accessible code, in favour of the recursive progression to 'compactness'.

Boden (1992) has described and demystified various aspects of creativity from a computational perspective. Boden (1993) broadly characterises creativity as the mapping, exploration and transformation of conceptual spaces. Mapping and exploration involve elaborating the conceptual space, filling in gaps either in the personal conceptual space, or historically. More dramatic changes involve transforming the conceptual space, in fundamental ways, so that a new conceptual space is created. Ideas which could not have been conceived within the previous conceptual space now become 'thinkable', an example of this (quoted by Boden 1992, 1993) being Schoenberg's creation of atonal music, opening up a new musical space, and allowing new

compositions which were inconceivable within the previous tonal music space.

Boden (1992) distinguishes between 'p-creative' ideas, those which are psychologically new to the individual and 'h-creative' ideas, which are historically new to humanity and have never been conceived before. Furthermore, the latter *could not* have been thought before as they require the creation of novel conceptual spaces.

Representational Redescription has been seen as a prerequisite of creativity. Karmiloff-Smith (1992) includes creativity in the flexible activities which, she claims, require redescribed knowledge. Boden (1992, 1993) also uses the concept of Representational Redescription. On her conception, higher levels of creativity involve the manipulation of 'mental maps' of conceptual spaces, and she suggests that Representational Redescription may be the method by which these maps are generated.

Unfortunately, there is a problem of circularity in using RR theory to explain creativity, because representational redescription is a creative process. It involves generating representations, *ex nihilo*, which had not existed previously in the mind of the individual. The 'chicken and egg' nature of the problem is revealed in the following quotation:

"It is the *capacity for creating* different representational formats of the same knowledge which enables inter-representational links that form the *seeds of human creativity*."

Karmiloff-Smith 1993 (p.29 emphasis added)

The circularity has emerged because both Boden (1992, 1993) and Karmiloff-Smith (1993) are concerned to account for the more advanced types of creativity. Boden (1992) is largely concerned to account for 'h-

creative' productions, as these are more generally thought to defy a computational analysis. However, she does acknowledge, in a general way, the role of p-creative processes in children:

"All human infants spontaneously transform their own conceptual space in fundamental ways, so that they come to be able to think thoughts of a kind which they could not have thought before. Their creative powers gradually increase, as they develop the ability to vary their behaviour in more and more flexible ways, and even to reflect on what they are doing."

Boden 1992 (p. 63)

The circularity of requiring representational redescription for the operation of creativity, collapses if representational redescription is defined as a creative process. There is then only a single phenomenon to explain and - although this is no easy task - this is the approach adopted in this chapter.

## 2.1 Creative processes

Boden (1992) distinguishes creativity from novelty. A generative system such as language can be used to produce an infinite number of novel utterances, but these are not creative as they *could* have been generated at any time. Creativity involves thinking something that *could not* have been thought by that person before, i.e. it involves a conceptual shift in thinking, a redescription of their representation. The generative system may then move up a level, and may generate the same output with a different level of understanding and different flexibility (e.g. a poetic conception of language, still allows the generation of everyday language). Different levels of knowledge will be discussed further in section 5.

## 2.2 Creativity in Development

Boden's (1992, 1993) insight that creativity involves thinking something that *could not* have been thought before, is illuminating for a developmental account. Adopting this approach means that children will be unable to understand or conceive certain things without Re-Representation. Children who have problems with Piaget's question (cited by Carey, and in chapter 8), "which word is longer snake or caterpillar?", are able to use words, but they don't know *that* they are using words. The children need to create the linguistic concept in order to understand the question, they need to re-represent the knowledge which is implicit in their language behaviour, and this may not become necessary until they learn to read.

Importantly for the 3R's model, Boden (1992) explains creativity without invoking qualitatively different processes in 'h-creative' people than in ordinary people. It is *knowledge*, and motivation, which are implicated. Adopting creativity as the basis of a representational redescription process, the 3R's model argues for just a knowledge differential between infants, children and adults. They could be employing the same basic Recursive Re-Representation process, although the domains to which they are applying them will obviously differ dramatically.

Stage theories of development argue that children of certain ages cannot think things that older children can. This is explained by Piaget (e.g. 1983) as a lack of logical operations in younger children. However, this developmental difference would also be predicted by Boden's (1992, 1993) approach to creativity. Creativity, involving the creation of new conceptual spaces, would predict discontinuities in development. Creativity allows children to think things which they could not think

before. Stages in understanding may well be an emergent property of knowledge development, when certain Re-Representations (e.g. those involving domains such as 'theory of mind') have widespread implications in a number of other domains.

### 2.3 Conceptual maps

Boden's (1992, 1993) concept of creativity as the 'mapping, exploring, and transforming' of conceptual spaces (abbreviated as METCS) is illustrated with isolated examples. There is no detailed analysis of what a 'map' of a conceptual space might be in cognitive terms. There seems, also, to be no overt distinction between cases where 'h-creative' people are operating on their conceptual spaces using their maps to guide them, or cases where they are operating directly on the maps themselves. Her initial definition of the concept is different again:

"'Maps' of conceptual spaces are internal representations, or descriptions, of the creator's *thinking-skills*"

Boden 1993 (p.23, emphasis added)

This definition seems to imply some representation of the cognitive processes involved in creativity, although this does not seem to be what she intends when she provides examples of creativity. Following the presentation of some transformations of conceptual spaces using heuristics she claims.

In these ways, and others, our *maps* of conceptual space can be explored, and even transformed.

Boden 1993 (p.23, emphasis added)

and later in the same article

"We have seen that creativity involves METCS: mapping the structures in one's mind, and using those maps to negotiate and transform the *conceptual spaces* concerned."

Boden 1993 (p.24, emphasis added)

In a developmental approach, it is important to define whether developments involve changing the conceptual spaces (using the maps as a guide), or changing the maps themselves. Boden (1992, 1993) would probably argue for changes at both levels, but as she does not elaborate the 'map' analogy in any great detail, it is not clear how the changes at different levels would relate. The differences are not important for her descriptions of h-creativity, but will be significant in a developmental model.

A further distinction, which needs to be made is the difference between an objective, and subjective conceptual space. The objective conceptual space will be the space of, for example, arithmetic. The subjective conceptual space, indicated by the individual's map, may be limited to say addition and subtraction. The 3R's model will extend the mapping analogy in section 5, from a developmental perspective. However, this extension may not be the conception of the process envisaged by Boden (1992, 1993). The 3R's model will view the child as operating in an objective conceptual space, using and extending her (higher level) map which indicates her subjective conceptual space. Re-Representation allows significant modifications to the map, and/or the creation of new maps.

## **2.4 Elements of creativity**

Boden's (1992, 1993) focus was not on development, and she has not applied her analysis of creativity to developmental issues, (apart from

representational redescription). In the following sections the general aspects of creativity which she has raised in relation to 'h-creativity' will be related to developmental issues and the empirical data from this thesis. Boden has identified a number of influences on the mapping of conceptual spaces, which she illustrates with examples of h-creativity. These are evaluation, constraints, analogical reasoning, and memory. Every stage of development and learning seems to require the creation of psychologically novel representations for the individual. If p-creative processes are central to development, then the fundamental features of creativity identified by Boden must be present from infancy. In the next sections we will describe the various processes which are implicated in adult creativity, and relate them to developmental data as far as possible.

In the following section Mandler's process of 'perceptual analysis' is described, which provides the basis for a representation creation process involving the elements identified in this section.

#### **2.4.1 Evaluation**

"Creativity, whether in children or adults, involves exploration and evaluation. The new idea must be compared to some pre-existing mental structure, and judged to be 'interesting' by the relevant criteria"

Boden 1992 (p. 63)

A computer could create novel combinations by just combining ideas in an exhaustive fashion, but this would be a generative rather than a creative system. What is essential for creativity, is having a basis for evaluating which of the combinations are worthwhile.

The importance of the evaluative component in creativity, is demonstrated, in the following anecdote. In 1992 a Manchester artist



submitted a painting produced by his 6-year-old grand-daughter to the Royal Academy. This was a largely fortuitous production, of five blobs of colour, which had merged and run down the page, the end result resembling 5 trees. The grand-daughter evaluated this production as a failure: her dots had run. The grandfather appreciated the pleasing image, and provided an evocative title to support his interpretation. The painting was duly exhibited amid a joyful outcry in the local media about the Art Establishment having been 'fooled'. However, this was not really the case. The creativity did not rest with the child: the production process was largely random. The creativity lay with the grand-father who, as an accomplished artist, recognised the qualities of colour and composition in the result. The grand-daughter must have produced a large number of paintings that *she* would have evaluated more favourably, but which the artist-grandfather did not bother to submit to the exhibition.

Boden (1992) stresses the point, that solutions to problems, or creative ideas are not solutions or creations unless they are *recognised* as such. In terms of h-creativity, there will be no basis for comparing the solution, in order to evaluate it. The solution must just fit in with the relevant background knowledge, and the subject's representation of the problem. Boden (1992) quotes the example of both Kepler and Copernicus who considered and rejected the idea of elliptical orbits. However, at a later stage Kepler re-evaluated the idea and came to see that this *was* the solution: Copernicus, however, did not. This illustrates that evaluation is relative to a state of knowledge in the individual, and it does not relate to the intrinsic merit of the idea itself.

A knowledge-based evaluation process means that children cannot create what they are not ready to create. They will not be able to extend,

or transform their conceptual spaces unless they can evaluate the new idea positively, regardless of the correctness of the idea itself. The evaluation component depending on the elaboration of the background knowledge of the subjects. In Copernicus' case, a good idea was considered, rejected, and abandoned. In terms of p-creativity, good ideas are unlikely to get lost. A good idea which is not appreciated by the child, will be presented again and again, until the child recognises its value. There will be a lot more direction of p-creativity, particularly in the school context.

If it were possible to assess the 'evaluation' component, it would indicate a child's 'readiness to Re-Represent', and might predict their future ability to create a new conceptual space. This idea is equivalent to Vygotsky's (1978) 'Zone of Proximal Development' which distinguished between children who produced the same level of performance when working alone. The differences in their likelihood to progress in the near future, was indicated in the extent to which they could benefit from adult guidance.

Evaluation of performance seems to be a continual cognitive process, comparing actual behaviour against anticipated behaviour. The drawing studies (chapter 3) indicated that even the youngest children tested were critical of their drawing productions relative to their expectations. The block balancing case studies (chapter 4), indicated that even when a child was bored, there was a continual prediction of behaviour which could lead to a 'surprise' observation.

#### **2.4.2 Constraints**

In addition to an evaluative component, Boden (1992) argues that constraints are essential to creativity.

"... far from being the antithesis of creativity, constraints on thinking are what make it possible."

Boden 1992 (p. 82)

Creativity may result from 'playing around', and combining unusual ideas. However it will never be entirely undirected, otherwise the creative idea would not be recognised as such. There may be a lot of 'ill-defined' elements involved in creativity, for example the goal may be expressed in very general terms e.g. to write a symphony, or to discover the chemical structure of a problematic molecule. However, there will always be a specific domain of concern, and possibly a specific question.

There has been a lot of recent interest in constraints in infancy. The general problem for infancy researchers is to explain how development initially gets started. The solution has been to suggest there are inbuilt constraints on learning (Gelman 1990a, 1990b). Keil (1990) argues that even the most hardened empiricist now has to accept that without constraints, learning would be impossible. It is generally acknowledged that infants are not faced with the 'blooming buzzing confusion' described by William James. Spelke (1990), for example, argues for a 'thingness' assumption, i.e. that the infant initially perceives 'things' in the world, and as a result can then associate movement patterns with them. The nature of the constraints hypothesized may vary, but there is general agreement that the infant is not a *tabula rasa*.

An important general constraint on the infant's perception is in terms of a limited central processing capacity. The limited ability of the infant to 'chunk' her perceptions will allow her to attend to only small portions of information and thus focus her experience. Newport (1990) appeals to absolute capacity limitations, as an influence on improved language learning in children. However, this may be equally explained

in terms of relative capacity limitations (different content of the chunks), and the latter position will be argued in the 3R's model (see section 4 below).

Another type of constraint on creativity is the use of heuristics. The majority of heuristics will be domain specific, and learned, and so may will be more applicable to adult creativity than to infancy. Some very general heuristics which include generalisation and specialisation may be operative from birth, however these will be closely linked to analogical reasoning processes (see section 3.3.3). One of Boden's (1992) general heuristics for exploring a conceptual space is certainly evident in young children, though, and that is the 'vary the variable' heuristic. This is used constantly in children's pretend play, for example, using a bottle top as a cup, is just a matter of varying the variable (trying 'bottle-top', in the 'cup slot' of a 'drinking schema'). Pretend play, may well be useful mapping out conceptual spaces, allowing young children to generalise their 'drinking schema', for example, and to extract out the essential elements. This kind of generalisation of the cup to a 'cup like object', may provide the basis for later analysing the ways in which the bottle top is like a cup. This will be the essential background elaboration for the subsequent creation of a more general concept of 'container'. There are clearly plenty of constraints in infancy, which could provide the basis for creative processes.

A large number of heuristics may be used consciously, by adults. Boden (1992) gives the example of a designer using a 'focus on the function' heuristic for generating ideas. This is a high level explicit strategy, which may be consciously communicated during training and will always have been used with awareness. Similarly, the child's 'vary the variable' heuristic may be explicitly represented. This use of

heuristics is less important developmentally, as their acquisition or progression to awareness will not differ from knowledge in any other domain.

### **2.4.3 Analogical reasoning**

Recognising analogies is a crucial element of creativity, and also in learning from experience, and concept formation. These fundamental reasoning processes seem to be operating from birth.

Goswami (1991) has argued that young children can solve analogies, if they have the relevant knowledge bases. She argues that previous studies fail to find analogical abilities in children, because the children fail to understand the content of the problem, rather than because they lack any reasoning ability. Brown (1990) has shown that 20 month old children were able to reason by analogy. They could select an appropriate tool from a set to retrieve a distant toy, based on a previous analogous experience. Goswami (1991) argues that there is no evidence of the development of the reasoning component<sup>1</sup>. This is compatible with the previous arguments in chapters 7 and 8.

Analogical reasoning requires the ability to analyse the various components of the domains in question. This has been demonstrated by Keil (1984) who argues that the ability to comprehend metaphors does not develop. He has found that children can understand metaphors if they have sufficient knowledge of both the domains, to be able to see the analogies between them. Otherwise they interpret them literally. The child needs a level of overview of the relevant

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<sup>1</sup> Goswami does argue for the development of 'metaknowledge', but we have explained this a knowledge development in chapters 2 and 8

knowledge, to extract the relevant elements, before analogies can be understood.

#### **2.4.4 Memory, Reminding and Prediction**

A fundamental feature of cognitive activity is long term memory. It seems unlikely that memory processes develop, but what can be remembered, will develop, as it depends on what can be encoded, which in turn will depend on background knowledge or perceptual constraints. Memory will clearly be much enhanced by the development of a system of symbolic representation, such as language. Memory is not under conscious control. With knowledge about memory, it becomes possible to actively search for some piece of information, or indeed consciously not to bother searching for that piece of information, also to employ strategies to induce better remembering. However, the underlying process of 'reminding' is not under direct control. It involves memories springing into awareness, through association with something perceived in the environment or something else in awareness. There is no reason why this kind of reminding process would not be operating from the moment there is something in long term memory to associate a stimulus with. Similarly, experience of any type will lay down some kind of trace in memory. This again is not under conscious control, it is not possible to refuse to remember an event, traces are laid down automatically.

Boden (1992) in a parenthetical comment states that

"reminding is a common source of creativity"

Boden 1992 (p.54)

In infancy, reminding may be the essential stage in creating the initial representations. As soon as the infant is reminded of anything, there is

a basis for representing the experience in some more general fashion. Reminding must involve unconsciously recognising some analogy with previous experience. Identifying the commonality, and representing this will provide the first 'concepts', which will in turn influence perception and subsequent behaviour.

The automatic process of memory and reminding leads to a constant expectation of what will happen next, based on the triggering of these memories. Mandler (1992) quotes an experiment by Watson (1972) indicating that 2 month infants could make a mobile move by pressing their heads on a pillow. After a number of repetitions, the infant began to expect the behaviour of the mobile and they produced more head presses than the control group because they had related the two events. These infants clearly have to have memory of both their own behaviour and the behaviour of the mobile to achieve this.

Mandler (1992) argues that the operation of a long term declarative memory is evident by 8 months of age (Baillargeon, De Vos, and Graber 1989, cited by Mandler 1992). There is no reason to suppose that memory is not operating even earlier than this. The acquisition of sign language has been shown to begin at 6 or 7 months of age, so that children at this age have associated a symbolic gesture with a meaning. This connection is earlier than for spoken language (Mandler 1988). This provides evidence that experience is being represented from a very young age, and that its onset does not require the development of qualitatively different conceptual structures.

#### **2.4.5. Creativity and problem solving**

As a slight aside, the connection between planning and problem-solving made in chapter 7, can equally be extended to creativity.

Boden's characterisation of creativity as a heuristic exploration of a conceptual space is very similar to Simon's characterisation of problem solving. Creativity could be thought of as problem solving in an ill-defined domain, and most problem-solving involves the creation of p-novel solutions. Isaev's planning task, reported in chapter 7, was novel for subjects and the solution would have been something which was p-creative. Creativity could be conceptualised as ill-defined problem solving particularly with an ill-defined goal state, although the starting state and operators may also be ill-defined.

### **3 Re-Representation through Perceptual Analysis**

In the previous section the elements identified by Boden (1992, 1993) as essential to creativity have been demonstrated in infants or young children. In this section, a mechanism which incorporates these elements, 'perceptual analysis' (Mandler (1988, 1992), is introduced. This account is of particular interest because it *creates* new representations, and because it was proposed for development in infancy. It will be shown that, in as far as the perceptual analysis process has been outlined, it incorporates very general cognitive process which can be generalized up the lifespan to form a recursive developmental mechanism.

#### **3.1 Mandler's model**

Mandler (1988) was concerned to explain the development of accessible conceptual representations in infancy. She argues that there is plenty of evidence for conceptual abilities in infants as young as six months, and consequently she rejects Piaget's idea of infancy as a *purely* sensorimotor stage in development. She suggests that there must be a



conceptual representation system in addition to a sensorimotor system in infancy, to explain the evidence of recall in infancy. Mandler (1988) has proposed that a conceptual representation system operates from birth, alongside the sensorimotor representational system. She also rejects Piaget's idea that conceptual knowledge is the result of a late developing ability to directly access the original sensorimotor representations. Instead she suggests that a perceptual analysis system creates *new* representations which are, by virtue of their conceptual nature, accessible. She proposes her theory of 'perceptual analysis' to explain how first concepts are formed.

Mandler's (1992) development of her original perceptual analysis account (Mandler 1988) concentrates on elaborating the initial representational format, which she claims are 'image schemas'. The 3R's account (at this stage in its development) will not align itself with any particular representational formalism, but will concentrate on generalising the processing element in relation to Boden's (1992, 1993) account of creativity, and concerns with cognitive flexibility.

Mandler (1988, 1992) does not elaborate the process element beyond the following description of perceptual analysis as:

"... a process in which a given perceptual array is attentively analyzed and a new kind of information is abstracted. The information is new in the sense that a piece of perceptual information is recoded into a nonperceptual form that represents a meaning. Sometimes perceptual analysis involves comparing one object with another, leading to conceptualising them as the same (or different) kinds of thing, but often it merely involves noticing some aspect of a stimulus that has not been noticed before."

Mandler 1992 (p. 589)

Mandler's (1988, 1992) model of perceptual analysis is conceived as a conscious process for creating symbols. She argues that there is evidence of symbolic activity in infants, if a symbol is defined as a vehicle of thought, rather than as a means of communication or external referencing. The initial symbols may be images rather than propositions, but crucially for her, they are interpretations and summaries of experience rather than just 'percepts'. The results of a 'perceptual analysis' are encoded as a new representation. Mandler (1988) stresses that this is an interpretation rather than a literal 'image' of the world, although it will be argued that this is an accepted feature of perception in general (see section 5.3). Perception is always a matter of interpretation, it is the balancing of top-down and bottom-up hypotheses.

Mandler's (1992) concept of the 'perceptual analysis' process, described in the above quotation, involves more than the interpretation of data through normal perceptual process. New conceptual representations are created by comparing two objects, either both perceived simultaneously or one currently perceived and one in memory. A new representation is created from the result of the comparison. This requires supplementing the normal perceptual processes with an ability to recognise analogies. Analogical reasoning was one of the basic features identified by Boden (1992) as necessary for creativity. There must also be some evaluation process, to prevent the construction of strange concepts based on irrelevant analogies, as not all the possible analogies will be represented. The whole process is a conscious one, and presumably occurs in working memory.

### 3.2 Perceptual analysis and RR metaprocesses

Perceptual analysis, in the 3R's model, plays the role of the endogenous metaprocesses in Karmiloff-Smith's (e.g. 1986) RR model, which generated the increasingly flexible representations. In the RR model, successive redescrptions of representations were produced by 'metaprocesses' operating directly over representations. The 3R's account needed to replace the RR 'metaprocesses' as they were phase-specific and linked to the different representational formats, which have also been dropped. The 3R's model adopts a parsimonious approach, suggesting that whatever processes account for the creation of the first representations will also account for the creation of later Re-Representations. Perceptual analysis is thus defined as a recursive creative process.

The empirical studies in chapters 4 and 7, indicated the importance of the perception and encoding of tasks, in allowing flexible performance. These elements are clearly central to the perceptual analysis process. In chapter 5, the purely endogenous nature of the RR metaprocess was rejected along with the notion of implicit information in representations. The perceptual analysis process overcomes these objections because it is an interactive process which extracts regularities from behaviour rather than from the representations themselves. Karmiloff-Smith's definition

"... representational redescription is a process by which implicit information *in* the mind subsequently becomes explicit knowledge *to* the mind ..."

Karmiloff-Smith 1992 (p. 18, emphasis in original)

can, thus, be paraphrased as: Recursive Re-Representation is a process by which implicit information in behaviour becomes explicitly represented.

### **3.3 Perceptual analysis as recursive constraint creation**

The basis of 'perceptual analysis' is perception. Neisser defines perception as "where cognition and reality meet." (Neisser 1976, p. 9). He stress the interdependence of mental and environmental process. Perception is an active, interpretative process for understanding the world. It is constrained by the external reality (bottom-up information), and the perceiver's past experience and anticipations (top-down information). The understanding which is achieved is the result of co-ordinating top-down and bottom-up information, and will necessarily be an interpretation, simplification and summarisation of the objective world.

The external world is not perceived in an objective way. There are a variety of filtering and selection systems which limit the information which enters the central executive. The physical perceptual systems limit the way in which a person interacts with the world. The size of human hands and the organisation of nerve endings limit the range of objects we can hold or feel, setting both upper and lower limits. The human eye is sensitive to certain wavelengths of light, so that it perceive patterns of colour (in contrast to a snake's eyes, for example, which perceive patterns of heat), and so on. Even after these initial structural filters, there would still be too much raw information entering though the sense organs. There needs to be further selection, based on the cognitive processor. Working memory has a limited capacity, and directs attention to the most important aspects of the stimulus, relative to the subjects goals. These kinds of selections of

information are variable (unlike the physical ones), based on goals and are under conscious control, for example, a person may choose to look at a lecturer or choose to look at other members of the audience. People are always purposive, even when the purpose is to relax and do nothing. In infancy there will be also be goals, although they may be very general, for example, distress-avoidance.

Top-down constraints also set up expectations of what is about to be perceived. These expectations are constantly operating and they depend on past experience and background knowledge. In infancy, the initial top-down expectations will be operating from birth. There is evidence of a disposition to attend to faces, (for example Johnson and Morton 1991). Spelke (1991) argues that the infant's expectations of objects include, for example solidity and continuity at least by 2<sup>1</sup>/<sub>2</sub> months. People always have some kind of expectation, allowing for the planning of activities towards a goal. The importance of knowledge in generating these expectations was demonstrated on the planning task (chapter 7), when Adam could not initially anticipate accurately the results of his actions, and could not plan to achieve his goals.

The constant prediction of experience is important in development, as it provides the basis for comparison. A mismatch between prediction and experience will generates a response (e.g. surprise) when the prediction (even the default prediction of 'no change') is not fulfilled. This will causes attention to be focussed on analysing the comparison to sort out the problem. If a new understanding is reached, it will stimulate a re-representation of the problem, changing the knowledge base so that future predictions will be different. The top-down component of perception will change with experience. This is what was observed in the planning task, differences in the problem

representation, not in the representational processes themselves. The *content* of the constraints differed with age and experience, but not the *process* of integrating background knowledge with bottom-up information to reach a perception.

The perception will be modified through the development of constraints: as knowledge increases, different constraints on perceptions will be created, allowing different things to be perceived, in a recursive fashion. To take an anecdotal example, Sophie (22 months) began using the phrase 'try again' to comment on her failure to fit a puzzle piece, and to anticipate her repetition of the puzzle-fitting behaviour. Prior to using the phrase, Sophie did keep trying when she failed to locate a piece correctly, however, having acquired the phrase, she now knows *that* she is 'trying again'. She has identified and labelled this aspect of her pre-existing behaviour, such that 'trying again' exists for her (initially in the single context), and she is able to recognise analogous instances of 'trying again' in other contexts, e.g. putting on shoes.

This is the notion of perceptual analysis in the 3R's model, that the observation of behaviour creates new constraints which in turn allow a new conception of behaviour. In the above example, the recognition was clearly prompted by the presence of the verbal symbol, but this will not always be the case. The new representation allows Sophie to perceive aspects of her behaviour that were not distinct prior to acquisition of the 'concept'.

### **3.4 Representational formats and codes**

Mandler (1988, 1992) envisaged, 'perceptual analysis' as comparable to Karmiloff-Smith's Representational Redescription approach, although they are concerned with different developmental stages. Mandler's

(1992) model, like Karmiloff-Smith's contains qualitatively different representational formats, she suggests that initial symbolic representations are in the form of 'image schemas' which are a halfway stage to a full conceptual representation. The different representational formats are necessary because Mandler wishes to maintain the idea of a separate inaccessible sensorimotor representational system.

"My sense is that most psychologists believe that there must be more than one representational format to the human mind. Reaching for an object is fundamentally different from having an image of that object ..."

Mandler 1988 (p. 131)

However, it is possible to have a number of different representational codes, without positing a separate sensorimotor format for infancy. There may be a number of different *codes* in memory, e.g. motor, linguistic, but these could still be developed through the same process of perceptual analysis. Scaife (1987) argues that the continuity between motor and cognitive processes is often overlooked in anglophone psychology. Recursive Re-Representation argues for a continuity of process, over different representational codes.

Karmiloff-Smith (1992) argues that the initial representation of knowledge is in a modality specific code. Later representational redescriptions extract information from the modality-specific codes and represent that information in a more general, and ultimately a linguistic code. The 3R's model will not be developed to the level of suggesting a representational format, it is equally compatible with a single representational format, or a set of parallel formats. However, the model will assume that there will be no qualitative changes in representational format with development and that whatever formats are proposed are present, and operative from birth. Recursive Re-

Representation processes operate through perception, and focus on behaviour rather than representations. The process can, thus, Re-Represent information generated by representations in one code into any other code.

Accessibility will not be attributed to one code or another, but to the level of description of the content (see section 5). Early concepts, the content of which will be mainly motor and sensory, may *become* automated, because they provide the basis for other concepts to be developed on top of them. Some early concepts may disappear because they are Re-Represented in a fundamentally different way. For example, some psycho-analytical approaches would argue for an early 'mother-self' concept, from which the 'self' has to be later differentiated (Sheila Spensley, personal communication). This concept of a 'mother-self' unit clearly has no place in the conceptual repertoire of adults, other than psycho-analysts. The latter would have a linguistic representation of the concept which would be quite different from the sensation-emotion-based concept they would have possessed as infants. The Re-Representation in terms of two separate 'mother' and 'self' concepts would eliminate the need for the original representational *content*, and would be independent of representational format.

Acquisition sequences in the 3R's model may involve decreasing as well as increasing flexibility. Re-Representation in a modality specific code or format, from a linguistic one will result in an automated, less accessible representation. This sequence happens in the acquisition of motor skills learned through originally verbal instructions e.g. typing. This relationship between Re-Representation and awareness is described further in subsequent sections, section 5 describing awareness



and section 6 relating knowledge levels to awareness. The next section briefly discusses surprise as the stimulus to redescription.

#### **4. Motivations for redescriptions**

Karmiloff-Smith has proposed that the stimulus to representational redescription is the internal stability of the relevant level of representation. As was noted in chapter 5, this is a problematic notion. Instead, it is suggested on the basis of observations from the block balancing and planning tasks that 'surprise' might be an alternative motivation. A surprising event would be the result of a mismatched comparison between the subjects prediction of events and the actual event (which might either be success or failure). This would then direct attention to the situation, stimulate perceptual analysis and ultimately a Re-Representation of the behaviour. The affective response would indicate the occurrence of a Re-Representation opportunity, but would not necessarily be causally implicated<sup>2</sup>. This is not to reject Karmiloff-Smith's idea that 'success' may be a stimulus to representational change, but to broaden the claim so that each occasion *subjectively* perceived as a success may stimulate a Re-Representation. In the drawing domain, for example there will be many such perceived successes.

Boden (1992) states that creative ideas are essentially 'surprising', but she distinguishes the surprise of the unexpected, from the surprise of the unpredictable. Re-Representation could be triggered by the latter type of surprise, which would be associated with a re-perception of a situation. The new perception would elaborate or transform the

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<sup>2</sup> There might be a causal role in a physiological account of the process or representational redescription.

conceptual space, which in turn would allow different expectations to be set up in the future.

## **5. Awareness**

RR theory states that knowledge is available to higher cognitive processes and awareness, only after redescription. Awareness only has access to knowledge re-coded into the E-ii or E-iii (linguistic) formats. Awareness itself is not explained. The 3R's account will take a different approach to the relationship between awareness and knowledge, focussing initially on characterising awareness rather than the knowledge representation. The first sub-section will describe the relationship between awareness and cognitive flexibility, as conceived in the 3R's model. The second sub-section discusses the development of 'automatic processes', which it will be argued develop beyond awareness.

### **5.1 Cognitive flexibility and awareness**

The 3R's account assumes that the basic cognitive processing mechanisms are operative from birth, the central structure being working memory. Working memory is conceived as a system for actively allocating attention (Baddeley 1990). The most important component of the working memory system is the central executive which is involved in all conscious cognitive processing, i.e. all the activities which require 'cognitive flexibility' such as, reasoning, problem solving, and planning. The important features of the central executive, from the 3R's perspective, are (a) that it has a limited capacity, and (b) that its contents are not restricted to any specific modality. The central executive functions to control behaviour,

maintain goals and to focus attention, filtering out distractions. It provides the arena within which knowledge can be manipulated. It relates background 'top down' information, goals and expectations to the incoming 'bottom-up' information which is coming in through the sensory systems and is the channel for inputting information into long term or semantic memory.

Awareness, on the 3R's account, will be attributed to the focus of attention, i.e. the contents of the central executive. It follows from this approach, that if the child or infant has a central executive, then she will be aware of something, whatever it is that the central executive contains. In infancy, this awareness will obviously not be verbal, and may not be much organised. At best, the initial contents of awareness will be limited to the perception of 'things' (Spelke 1990). It most certainly will not contain linguistic representations, although it will be argued, with Mandler (1988), that very early on it will contain symbolic representations.

As knowledge develops through recursive re-representations, the infant is increasingly able to organise her perceptions. She will perceive, and become aware of her activities, such that she can think things which she could not think before. For example, the sensations associated with 'feeding' will be differentiated into components of 'sucking' and 'nipple'. This development occurs through sensations being categorised (using perceptual analysis) and being 'recursively re-represented' into increasingly compact 'chunks'. The contents of awareness or the central executive will then effectively increase in terms of the objective amount of information it contains (see section 5.1 for more on chunking) and this information will allow flexibility at a higher level. In adulthood, the contents of awareness will

predominantly relate to verbally encoded knowledge, as it is obviously the most compact method of representing information. This will not be the case in infancy, although the infant's concepts will develop through the same Recursive Re-Representational mechanisms.

The central executive has a major role in the 3R's conception of cognitive flexibility. It will be argued that higher cognitive processes such as planning, which require flexible representations, can operate only over the contents of the central executive. These processes in adulthood will often operate over linguistic representations, but it will be argued that the same higher cognitive processes also operate more generally over the contents of awareness whatever the representational code. In keeping with the working memory conception, the central executive is not modality specific.

RR theory involves four levels of knowledge, with only the two highest levels being available to awareness, accessibility being a feature of the formats themselves. Following from the equation of awareness with the central executive in working memory model, the 3R's account characterises the accessibility of knowledge in terms of its level of 'chunking'. The concept of chunking in the 3R's model is described in more detail in section 6.1.

## **5.2 From Awareness to Automaticity**

In the 3R's account, awareness is restricted to chunks of a specific 'granularity' in the knowledge hierarchy. As an activity is 'chunked', it can be executed with less attention to the constituent parts. As layers of representation are created on top, the lower levels are Re-Represented in a summary form where awareness will not attend to their execution. This simplification/generality trade off was also a feature of Karmiloff-

Smith's conception of Representational Redescription. If the original lower levels of detailed representations are no longer accessed they may simply decay. The representations then become opaque, this process may account for the inaccessibility of many motor skills. The recursive process of 'chunking' will create sub-levels which then slip below the level of awareness, and become automatic.

## **6 Levels of knowledge**

In this section the progression through levels of knowledge and their relationship to awareness is described. Cognitive flexibility is associated with a certain level of chunking, and domain elaboration, such that an overview, or map can be created. Re-Representation can occur within levels (elaborating or extending the conceptual space), or it can create new levels, creating new conceptual spaces. The latter potentially leading to developmental discontinuities.

The basic developmental progression is one of chunking, and this process is described in the first section. In the second section different levels of knowledge are described, in terms of their relationship to awareness, this being similar to the distinction proposed in Activity theory (Leont'ev 1981). In the third section, the interaction of levels of knowledge will be demonstrated by extending Boden's (1992, 1993) mapping analogy.

### **6.1 Chunking process**

The concept of 'chunking' is well established, although underspecified, within Cognitive Psychology, however, it does not often appear within the developmental literature (but see Klahr, Langley and Neches 1987 for exceptions). The initial concept was proposed by Miller (1956), who

discovered that the capacity of short term memory is limited, not in terms of an absolute quantity of information, but by some unit of information organisation: a 'chunk'. Thus, adults who can remember a sequence of 7 random letters of the alphabet, could also remember a list of 7 words (which obviously contain many more letters) because these letters are organised into meaningful 'chunks' in long term memory. In the same way, many more letters would be recalled if they were contained in a list of well known phrases. Proverbs, for example "a stitch in time saves nine", "a bird in the hand is worth two in the bush", would each be familiar enough to form a single chunk for most people. It is not clear how the 'chunking' process operates, but it is clearly a recursive process.

Chunking is a feature of expertise, which can be most convincingly demonstrated in a restricted domain such as chess. De Groot (1966) and Chase and Simon (1973) have shown that experienced chess players exhibit superior memory for the positions of chess pieces than novices when they are presented on a chess board in arrangements taken from real chess games. This improvement in memory was not due to any superiority in the experts' memory capacity, as the difference between novices and experts disappeared when random arrangements of chess pieces were presented. The performance difference was due to the experts ability to 'chunk' the information into meaningful strategic groupings, which enabled them to recall the position of more pieces. The difference has been shown to persist between child-chess experts and adult novices, indicating that chunking is purely a function of knowledge, and is not affected by 'developmental level' (as argued in chapter 8).

It is generally accepted that there is a limit to the amount of information that can be held in 'working memory', the limit being set in 'chunks' rather than any objective measure of information. There is some confusion about what the actual capacity in chunks is. Miller (1956) suggested that the capacity of the central processor was limited, to seven (plus or minus 2) 'chunks' of information. Simon (1981) has argued that the range of capacities which have since been suggested by himself (5 chunks, Simon 1974) and others (ranging between 4 and 10) is rather too wide for comfort. The 3R's account will remain agnostic as to the absolute capacity in chunks as this debate will not affect the argument here. The 3R's model will be developed at a level of generality which requires merely that there is a limit. In absolute terms, the quantity of information which will be in awareness will depend on how the person is able to encode the environment. This, in turn, will depend on the level of 'chunking' of the relevant knowledge, which provides the top-down constraints on perception.

Chunked knowledge is hierarchically structured, the higher levels encompassing more knowledge in absolute terms than the lower levels. On the 3R's account, the (recursive) chunking of knowledge will thus increase the contents of awareness, allowing larger portions of knowledge to be in awareness. An important consideration for the 3R's account is that 'chunking' is always into units of *meaning* for the individual. There are no examples of people being able to chunk arbitrary parts of experience, or random number sequences without

imposing some meaning on them<sup>3</sup>. Re-Representation of new chunks, then must include an evaluation component. The operationalisation of 'chunking' will be discussed in section 8 in relation to a production system model of development: the BAIRN system (Wallace, Klahr, and Bluff 1987).

## **6.2 Levels of knowledge and awareness**

The RR model included different representational formats which differed in terms of their accessibility to awareness. In the 3R's model there is no qualitative difference between levels of redescription, but the interaction with capacity limitations will lead to differences in the contents of awareness. Levels of knowledge description relative to the capacity of awareness will then explain cognitive flexibility in a domain.

Chunking, as was argued above is always into units of meaning. These meanings will largely be shared between individuals, as they are interpreting similar environments through the same encoding and processing mechanisms. In the initial stages of development there will be a predictable sequence of development, as initially the infant must represent her own body, and because the 'top-down' perceptual component will be limited. It is literally not possible to run before you can walk. At higher levels it will not be possible to predict rigid sequences, although at a general level within a domain there will be a natural progression in knowledge development, it is necessary to know the rules of chess before you can understand chess strategies.

In this section, a division into three main levels of chunking of knowledge will be distinguished. These are subjective divisions

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<sup>3</sup> Neisser (1981) presents a collection of examples of mnemonists capable of great memorial feats. All subjects had a great deal of domain specific knowledge and/or strategies for making random material into meaningful images.



differing in terms of the relationship between the individual's knowledge and awareness. The three levels are basically those described by Activity theory (Leont'ev, 1981; Draper<sup>4</sup> 1993), and the characterisation of the levels in terms of the allocation of attention is very similar to it. However, because the 3R's model is concerned with the role of information processing and representational change, the distinction will be used quite differently. To avoid confusion with an Activity theory account, a different terminology will be adopted.

The focus of awareness in normal functioning will be called the *task*<sup>5</sup> level. If a person was asked what she was doing, this would be what she would generally report. To take an example from cookery, a *task* might be 'chopping an onion'. The *task* will generally be contributing to some higher level *goal*, in this example making a pasta sauce. Although the *goal* level will organise the *task* level, providing a 'map', it will not itself be the constant focus of attention. *Goals* direct the activity, and may also be part of a hierarchy of *goals*, in this example a higher level *goal* might be 'produce a nutritionally-balanced meal'.

Below the task level will be the *constituent* level. These lower level actions will generally be executed automatically without awareness. In this example, a *constituent* would be 'holding the knife'. The *constituent* level might, temporarily, be brought to the focus of awareness if something went wrong. For example, if the execution of the chopping task was disrupted by an oily knife which was hard to grip. However, once the problem had been remedied, attention would once again focus at the *task* level.

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<sup>4</sup> I thank Dr. S. Draper for directing me towards Activity Theory, although he bears no responsibility for this interpretation.

<sup>5</sup> Italics will be used to distinguish references to the specific definition of these terms from the more general usage of the words.

In a developmental context, the 3R's model will argue that what is a *constituent* for an adult may well be a *goal* or a *task* for a younger child. For some adults, 'getting dressed' might be a *task* serving the higher *goal* of getting off to work in a hurry. Little thought will be given to the motor processes, or the sequencing of items once the clothes have been selected. For other adults getting dressed might be raised to the level of a *goal*, when concerns about appropriateness, colour-coordination and achieving a 'look' are added to purely functional considerations. More attention will then be directed to certain *tasks*, e.g. putting on sheer tights without laddering them. In contrast, for a toddler, putting on your socks is a considerable problem, and would probably constitute a *goal*. Putting on your socks, requires holding the socks so that there is an opening at the top, orienting the sock so that the heel is pulled over the sole of the foot etc. all of which require conscious attention. For an adult these aspects would form *constituents*, or even *sub-constituents* which are automatically executed without awareness. The *constituents* for the young children would be gripping the sock with the finger and thumb, for example. Consequently, the complete 'getting dressed' process has to be scaffolded by an adult, because it does not exist as a goal for the child. There would be no continuation to the next dressing step without direction. At a developmentally earlier stage, even the *task* of putting on you socks would be entirely out of conceptual range, when the grasping of any object was the *goal*.

As development proceeds, and new *goals* are created, there will be *constituents* which drop below the awareness window as knowledge levels are created above them. The gripping *constituent* in the above example for a young child will be a sub- or a sub-sub-*constituent* for an adult and so on. The lowest levels will operate automatically, and their execution will not place any load on working memory capacity. In the

example of gripping an object, there will have to be continuous adjustments made between the hand and the object to get the grip right, but in the adult, all of these processes will operate entirely without awareness. The argument is that, however, in infancy, these processes did require attention, at some stage 'gripping a particular object was a *goal*. Here again it is argued, with Scaife (1987), that there is a continuity between motor and cognitive development. Many of the motor skills are fundamental building blocks of other activities, and have therefore *become* constituents, with the result that they are inaccessible. Although they will initially have been acquired with awareness.

In the RR model, Karmiloff-Smith claims that lower levels of procedural representation are not lost, but can be accessed when required. This is not a feature of the 3R's model, an old representation will be replaced by a redescribed one, unless there is a distinct reason to maintain it. At this point, though, the RR model is talking about much higher levels of knowledge than the 3R's model. An example of the loss of earlier representations is the process of tying a bow. Bow tying is a *constituent*, of many activities and is executed automatically. At some stage, though, it must have been consciously learned, in all probability with some verbal instruction. This verbal description is lost, as the bow tying process becomes automatic. As in skill acquisition, the process has been represented as an automatic, non-verbal motor procedure. On the 3R's account this is because it has been re-represented in a compact motor format which will allow the original linguistic representation to decay with lack of use. If an adult is asked to describe how they tie a bow, the process has become opaque and they have to carry out the operation and describe the resulting actions. If they have no string with which to tie a bow, they gesture with their hands. If made to sit on their

hands, they are compelled to move their heads<sup>6</sup>. Levels below the constituent may be considered to have become compiled, and many motor skills will be in this category. However, if required attention can always be focussed on the detail of the constituent through the execution and observation of the behaviour, as in the bow-tying example.

The description of levels in this section is clearly an idealisation, particularly for more complex knowledge domains. There will not be a neat hierarchical progression from one level to another. *Tasks* under any one *goal* may be 'automated' to become *operations* at different times. The interaction between levels will be described in the next section.

### 6.3 Interaction of knowledge levels

The interaction of levels can be indicated by extending Boden's mapping analogy. In terms of attention an individual operates at the *task* level, which exists in an objective conceptual space. The individual's map, indicates their subjective conceptual space and provides the context for their *goal*. The *goal* level itself, may or may not be mapped, depending on whether the individual is directing attention to the highest level of conceptual space which she possess, or to a lower level. Flexibility requires having a map of the domain, an overview, but this does not preclude operating (relatively inflexibly) at higher levels where no map yet exists.

Recursive Re-Representation involves the creation of new conceptual spaces, and the elaboration of existing ones, both types of

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<sup>6</sup> This claim is made on the basis of a small study carried out in 1983 by the author as research assistant to Prof. J. Annett. The interpretation, however, is the author's.

change will be illustrated in the following hypothetical example. An infant might have a map of a room or several isolated rooms in a house, marked for example with 'places I can pull myself up'. This will enable her to get from any place within that room, to a place where she can pull herself up. However, this is the limit of her flexibility. This does not disbar the infant from *recognising* routes between rooms, e.g. up to the bathroom or to the bedroom, but she would not either conceive of goals such as 'get to the bathroom' or have her knowledge represented in terms of 'rooms' such that the relationships between the rooms in the house would make any sense.

An older child would have dispensed with 'places to pull yourself up', and would have marked different items on her maps of the rooms with the locations of toys, television etc. instead. She would also have maps of the various other rooms, at various levels of detail, and a selection of routes between the rooms. At some stage, this elaboration would allow a re-representation of the information, in terms of a map of the house (a new conceptual space) which would co-ordinate the relationships between rooms. This would allow the child to conceive and pursue 'in-house' goals from any starting point within the house, i.e. to generate as well as recognise routes within the house. This overview does not require that each room is known in the same depth. The mother's study might be 'off-limits' and thus known in little detail (indeed it might or might not be included in the child's subjective house map). However, mapping at this level would entail representing the rooms, as 'rooms', taking a global perspective on her previous knowledge of the contents of individual rooms. As an infant, she was objectively operating within rooms, within a house, but did not know *that* she was operating in a 'room' or, *a fortiori*, a 'house'.

Creating a house 'map' would allow a child to explore other people's houses, by analogy, and to predict that they might also contain bathrooms and kitchens. This would also allow 'in-house' goals to be transferred and executed in other people's houses. Similarities and differences between people's houses would allow for elaboration and refinement of concepts, e.g. a house with a bathroom downstairs, might remove the 'location=upstairs' feature from a bathroom concept, stimulating a Re-Representation of the concept, but without the creation of a new conceptual space. Such elaborations would, in turn, change 'bathroom-seeking-behaviour' in the child. This information would be surprising, and would be different from acquiring new information which could be perceived in terms of the existing bathroom concept. At the same time as the child is creating a 'house map' she would not have a map of her village. She might well have an entirely flexible (if perhaps faulty) map of her own house co-existing with knowledge of specific routes within the village, e.g. to often-visited friends' houses and to the sweet shop. She could possibly generate these particular routes, in a step by step fashion (indicating a minimal context-dependent map), however she would not initially be able to generate a novel route, for example from the sweet shop to a particular friend's house. However, whilst lacking a detailed map at the level of her village, she might also recognise regular trips made between villages, although she might be unable to generate these at all (not having encoded the relevant landmarks).

Mapping of domains could continue indefinitely, varying both in detail, e.g. between a road map of the area and an ordinance survey map. Both maps would allow the holder to get from place to place, however, the ordinance-survey-map holder could consider the gradient of a potential route, for example, as well as its directness. A higher level

of map would place the area within a whole county or country, and so on, allowing trips across the world to be considered, which were entirely inconceivable to the infant or child. However, when thinking about a trip across the world, you do not plan at the level of first 'find the front door in your house', this level is just automatic.

#### **6.4 Flexibility and knowledge levels**

Cognitive flexibility, in the 3R's model, will be influenced by two main factors. The first is the presence or absence of a map or overviews of the relevant domain knowledge, and the second is the level of chunking within a knowledge level, and whether it leaves space for other elements to be considered in parallel. In this section, examples from the empirical work reported earlier in the thesis are described in terms of the 3R's model.

In chapter 3 (section 1), Karmiloff-Smith's 'draw a strange man' task was shown to produce different levels of flexibility in children. The younger children were able to create 'strange' drawings by deleting elements, or changing the shape of the elements in their drawings. The older children were also able to add extra elements, either from the same or a different category, or to swap elements within a drawing. On the 3R's account, the younger children had a map for drawing their man, which existed in isolation from other drawing maps, e.g. house drawing. This was a map of the *task* level, but the *goal* level was not mapped. The *task* map would allow them to appreciate the relationship of elements within their drawing of a man, to produce them in any order, and to apply their creativity to any of the chunks within the man drawing, e.g. 'head'. The drawing production would be using the contextual relationships between the elements in the drawing to organise the drawing, however these relationships would not

themselves be represented. The older children would have this higher level overview of 'man drawing' (a map of the *goal* level) which would allow them to operate with the relationships between parts (e.g. to change the orientation of elements) or to compare the relationship of elements between two drawings, (e.g. man has legs, pig has a trotters). This level of comparison allows them to be flexible at a higher level.

In the drawing task (Chapter 3, section 6) children were asked to make specific modifications, e.g. "draw a man with too many of something.", and were provided with examples of these modifications (e.g. a man with two heads). The younger children tested with this task were able to produce the appropriate modifications. This task does not require the overview as the modifications had been mapped out for the children, and the task transformed into one of making a local contextual change which they were able to perform. However, the youngest children did not create their own variants of the example modifications, whereas the older children did (see chapter 10 for a suggested further study of this difference).

The block balancing task illustrates the difference between wandering in a conceptual space and having a map. In the block balancing task there are complex interactions between weight and distance. Full knowledge of the balancing process requires understanding of all the interactions between the elements, creating an overview or map of the domain. When this is achieved, a prediction can be made for a novel problem, which can be encoded in terms of an analysis of the appropriate features of the block (ignoring irrelevancies e.g. which bit of the bar it is balancing on).

The fixed idea that things balance in the centre, which may well be developed from exposure to salient examples in school, is limiting



because it does not map the domain, it provides a single route. Karmiloff-Smith and Inhelder (1974) characterised this as a theory, but a theory is like a map, which may be wrong but should allow exploration in a domain. The centre 'theory' is inflexible because it limits concern only to one variable, the 'length' of the block, and prevents consideration of other variables. When a map is created, the whole system is understood. The response will be more flexible, as the relationships between the elements are understood. The child will balance the block, and will understand *why* it balances, allowing the principle to be used creatively.

## 7. BAIRN system

The BAIRN system devised by Wallace, Klahr and Bluff (1987) is proposed as a complete model of cognitive development. It is a knowledge development model, and it includes a number of the features which have been identified in the 3R's model above. BAIRN relates to the knowledge development aspect of the 3R's model, although it is not concerned with the perceptual analysis mechanism. However, it might provide a useful basis for further development of the 3R's model. The basic approach is one of Recursive Re-Representation in that new representations are created, and these are based on the results of observing performance.

The points of similarity between BAIRN and the 3R's model are raised in general terms this section, based on the verbal description provided in Wallace, Klahr and Bluff (1987). A more detailed evaluation of the model would require analysis of the program itself, or ideally a re-implementation of it. The strength of the BAIRN model arises from the complex communications between nodes, and these are

difficult to evaluate from a written description. BAIRN is a very wide ranging system with many different mechanisms included. Some of these will inevitably be operating as 'place holders' rather than principled components of the system. Surprisingly, no-one seems to have developed this model since the initial report<sup>7</sup>. The system would certainly require assessment in more than the single domain, 'conservation of discontinuous quantity', which has been used to describe the model.

BAIRN uses a production system architecture, but it departs from the normal approach of a single level of productions interacting only through the working memory. BAIRN uses the 'node' as the basic unit of knowledge, rather than the production, and these are arranged in a hierarchy. Each node contains a small production system, as well as other information which relates it to other nodes. Development occurs through the creation of new nodes, either at a more general or a more specific level than the originating node. Such learning is based on the observation of the results of actions, stored in an episodic memory.

## 7.1 Knowledge representation

A node consists of three elements: a definition list, an experience list, and a description list. The definition list contains two parts: the *activation conditions* for the node, and the *production set*. The *activation conditions* contains the condition sections of some of the production rules from the *production set*. The production rules whose conditions are selected, are those which have formed the first element in a successful operation of the node's complete *production set*. When some of the *activation conditions* are matched by information in the

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<sup>7</sup> A search through the Psychological Abstracts (Silver Platter) and the BIDS citation system produced no references to Wallace, Klahr, & Bluff (1987) or to BAIRN.

work space, BAIRN searches for information to satisfy the other activation conditions. It is an active model, rather than passively driven by the contents of working memory.

The *production set* contains both procedural and declarative knowledge. These co-exist at node level, rather than forming two distinct systems (e.g. Anderson 1983). The declarative knowledge is envisaged as consisting of rules and semi-rules, the former "short-circuiting" the procedural productions, by linking specific conditions with a final result. The semi-rules, rather than producing a final result, produce an intermediate state. Declarative knowledge can be acquired either by analysing the results of the procedural productions, which leads to context-specific rules, or it can be created directly from linguistic input. A progression from procedural to declarative knowledge is proposed in the model, and this would accord with Karmiloff-Smith's basic intuition about Representational Redescription: a development from 'knowing how' to 'knowing that'.

A large part of the material stored in a node relates to the context of execution of the node. This allows for the generalisation and specialisation of nodes, based on their functional relatedness and temporal contiguity with other nodes. This emphasis on context and the relationship to other nodes is entirely lacking in the opaque procedures proposed in the RR model (a problem raised in chapter 5). In BAIRN the functional relatedness of nodes is crucial to the Re-Representation of behaviour and is represented within the nodes themselves.

## 7.2 Capacity Limitations and Awareness

BAIRN uses the concept of capacity limitations to limit the processing channels to 3 parallel channels, with only one being "focally conscious". The other two channels are 'unconsciously processed' with only their results being attended to. The central work space is limited: the short term memory capacity being 10 chunks, however, both these limitations have been determined by implementation considerations rather than directly by psychological study - beyond the acknowledgement that there are limits.

In addition to the limitations on central workspace, BAIRN has unlimited work spaces for each node. This, it is argued reflects the unlimited nature of LTM. However, this seems to be a psychologically unmotivated feature of the model: LTM is usually envisaged as unlimited in terms of storage rather than allowing additional processing. This issue would require critical assessment in any re-implementation.

The main capacity restriction in BAIRN, is glossed as relating to 'focal consciousness', this relation between capacity limitations and awareness was also described in the 3R's model. An interesting feature of 'focal consciousness' in the model is the spread of attention to the level below the node in question. The time line (episodic memory) records the results of the operation of the nodes below the focal node, and can use this information to eliminate redundancies, or create new nodes. This has a basic similarity to the knowledge levels described in section 6.2, where flexibility, due to the creation of new *goals* and the resultant ability to operate at a higher knowledge level, allows the space for lower levels to be re-perceived, and thus re-represented.

The two nodes which are unconsciously processed in parallel with the focal node do not create an elaborated record, unless they are raised to 'focal consciousness' during their processing. 'Focal consciousness' does not affect the processing of the node, but is implemented as affecting the time line record, and the semantic STM entries i.e. its effects are only distinct at the completion of processing. The 3R's model has nothing to say about unconscious processing (at this stage in its development), but the use of two unconscious channels in BAIRN seems somewhat arbitrary.

### 7.3 Top down processing

The influence of top down processing in BAIRN is captured by the fact that it can initiate search for elements which are the unsatisfied preconditions for a node, rather than just passively responding to the contents of the work space. The general effect of experience is captured by the notion of spreading activation, following successful execution.

Spreading activation is achieved by passing *information* (rather than an activation potential) to other nodes, from the results of a processing step. BAIRN differentiates three types of spreading activation which are operative during normal states of arousal, but these are restricted in states of high and low arousal. In high arousal the spread of activation focuses on the two 'depth' approaches, following the line of the current processing direction. In states of low arousal, the emphasis is on the 'breadth' approach and switching processing direction. This fits in with Boden's (1992) observation that creative combinations often occur in states of low arousal, even during sleep. Creativity often results from connections being made between apparently diverse domains.

## **7.4 Evaluation**

Evaluation was shown to be a crucial element of creativity (see section 2.4.1). An interesting element of BAIRN is that it evaluates the outcome of a node's execution, as consistent or inconsistent with its expectations. The 3R's model includes a continual element of prediction of behaviour, with surprise suggested as a stimulus to redescription. This finds a connection in BAIRN, where 'surprise' seems to be implicit in the recognition of 'unexpected-ness'. However, in BAIRN the evaluation leads to a highlighted representation on the time line, rather than any immediate representational reformulation. The experimental data from the block balancing task, would indicate that if immediate processing did not produce some reformulation, then the 'surprise' rapidly decayed rather than remaining a feature of the time line.

## **7.5 Constraints**

The notion of constraints on action and representation is captured in BAIRN by 'motive generators' which determine the goals of the system. How these elements of the system are implemented is not clear from the description provided. However, highly significant motives are able to cause new nodes to be created from a single occurrence of a behavioural sequence.

## **7.6 Knowledge development and learning**

BAIRN has four basic learning processes, all of which use information which is recorded in the time line (or episodic memory). Two of the learning processes create new nodes, and two update the contents of nodes. These broadly correspond to the 'within-level' and 'between-level' Re-Representations distinguished in the 3R's model.

New nodes are created at both higher and lower levels in the hierarchy. Higher level node creation occurs through the detection of patterns of information re-occurring in the time line. The basis of the redescription is the temporal proximity of the operation of two nodes. Nodes can also be combined if they are found to be functionally equivalent. In this case a super-ordinate node is also created. Over-general initial representations can also be replaced with more specific lower level distinctions.

The 'within level' processes in BAIRN, are redundancy elimination and node modification. The former processes modify productions to eliminate unnecessary production calls. The node modification processes will either add new productions to a node reflecting in regular co-occurrence with other nodes or it will review the connections of subordinate nodes following the creation of a new super-ordinate node and will substitute the new super-ordinate node name (where relevant) instead of the sub-ordinate node names.

## **7.7 Conclusion**

The BAIRN system contains many of the elements referred to in the description of the 3R's model. It appears to be an impressive system and may provide a useful starting point for formalising the 3R's model. However, without a re-implementation is hard to evaluate the system in depth. The lack of published replications or developments may indicate others have failed to reproduce the system or that BAIRN did not generalise to other domains.

Any current A.I. system necessarily involves a simplification of behaviour. The 'creative' processes in BAIRN are much simpler than those described by Boden (1992). However, the model is a creative one,

which in keeping with the 3R's theory, produces a hierarchy of structurally similar nodes, rather than the qualitatively different formats suggested by Karmiloff-Smith (e.g. 1986). Boden's (1992) computational account of creativity would provide a useful direction in which to guide the development of BAIRN, if it was found to be a sound basic system.

## 8. Summary

In this chapter 'Recursive Re-Representation' was proposed as an alternative to the Representational Redescription (Karmiloff-Smith 1986). Representational Redescription was criticised earlier in this thesis, both on empirical and theoretical ground, and significant changes to the theory have been proposed. However, the underlying principle of repeated representation is maintained as the explanation of increasing cognitive flexibility. Cognitive flexibility, on the 3R's account being restricted to the limited capacity central processor, with Re-Representation providing new compact knowledge representations, or 'chunks'. Recursive Re-Representation is presented as a creative process (rather than an explanation of creativity), which operates recursively from birth (eliminating the stage of 'behavioural success'). The 3R's theory replaces RR theory's endogenous metaprocess and the redescription of 'implicit' information represented opaquely within procedures, with a perceptual analysis process. Perceptual analysis, re-represents behaviour rather than representations, making the 3R's model more interactive than the RR model. Development was shown to be the creation of higher levels of knowledge, which allow the child to conceive things that could not have been conceived before. The 3R's model is proposed both as a lifespan developmental mechanism and as



a more parsimonious account of the development of cognitive flexibility.

## Chapter 10

### Conclusions and recommendations for future work

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#### 1. Contributions of this thesis

This thesis began by analysing cognitive flexibility, and rejecting the approaches based on the concept of 'metacognition'. The most promising account of the development of cognitive flexibility was that of Karmiloff-Smith (1986), whose Representational Redescription (RR) model has been analysed in great detail in this thesis. Two of Karmiloff-Smith's tasks: children's drawing (1990) and block balancing (1984; Karmiloff-Smith and Inhelder 1974) were extended and the results were not found to support the Representational Redescription model (1986). However, both experiments provided evidence of developmental changes and useful insights for the development of the Recursive Re-Representation model. The conclusions rejected the procedural-format of initial representations; queried the concept of behavioural success; stressed the importance of encoding; and suggested that 'surprise' might be a stimulus to redescription. The empirical data were broadly consistent with a knowledge development approach, but the development of planning and creativity were also hypothesized.

A rigorous analysis of Karmiloff-Smith's (1986) most detailed account of Representational Redescription was carried out from an implementational perspective. Various other aspects of the model were

criticised, including the endogenous nature of the redescription processes and the concept of implicitly *represented* information. A more interactive approach was proposed, with information being implicit in *behaviour*. It was suggested that the concept of 'behavioural success' might be an unnecessary limitation of the RR approach, although dropping this constraint has serious repercussions for the model. The four representational formats (which had been criticised) have to be dropped, the series of metaprocesses replaced with a recursive processes, and the problematic concept of 'stability' as the spur to redescription replaced. The promise of this butchery, is that a recursive model of representational redescription can then be considered as a general cognitive development mechanism.

The recursive generalisation of representational redescription produces a knowledge development account of cognitive development. This approach is suggested as the most parsimonious and was supported by a literature review. However, the alternative option of process development was considered, with an analysis of planning development. A review of the literature found only descriptive accounts, apart from the socio-cultural approach which suggested internalisation as the developmental mechanism. Isaev's (1985) model of planning development was pursued with a replication of his planning task, however the empirical data were shown to be consistent with a knowledge development explanation, performance decrementing with increased cognitive load, rather than with age.

Representational Redescription was approached from various angles in this thesis, and the analyses and criticisms provided the basis for the development of a new model. The basic concept of representational redescription was not rejected. Recursive Re-Representation begins by

viewing representational redescription as a *creative* process, and uses Boden's (1992, 1993) computational approach to creativity as a basis, and draws on Mandler's (1988, 1992) account of perceptual analysis in infancy. Cognitive flexibility is equated with the contents of working memory, developing flexibility in a domain is explained through the creation of new levels of the knowledge hierarchy and chunking. The groundwork has been laid and it is now clear that Recursive Re-Representation should be fully specified, using the BAIRN system (Wallace, Klahr, & Bluff 1987) as a basis and focusing on the creative nature of redescrptions.

In the following three sections general avenues for further research are identified, and in section 5 some specific further studies are suggested.

## **2. Recursive Re-Representation and BAIRN**

The mechanisms of the 3R's model are specified only in general terms. Ideally, the model should be implemented as an A.I. program to clarify its operation and to develop the account. The BAIRN system (Wallace, Klahr and Bluff 1987) was proposed in chapter 9 as a promising starting point for developing the model. It was hard to evaluate the psychological validity of BAIRN from the verbal description in Wallace, Klahr and Bluff (1987). The model has, in any case, only been implemented in one domain and it would need to be generalised to other domains. Certain elements, such as the capacity limitations, three processing channels and unlimited node-level processing were somewhat arbitrary, based on the needs of the implementation rather than on any psychological considerations. A re-implementation would

clarify which elements of the theory were principled (an approach advocated by Ritchie and Hanna, 1984).

It is possible that a different representational format, from the production system architecture, e.g. Nelson's Generalised Event Representations (Hudson and Fivush 1991) would be worth considering. The system also needs to be extended to include the perceptual analysis mechanism of the 3R's theory. A study to be proposed in section 5.2, would allow a more detailed analysis of knowledge development in the block balancing task and this might provide a useful domain for a re-implementation.

### **3. Development and Creativity**

Boden's (1992, 1993) computational approach to creativity, is illuminating in presenting creativity as tractable. Pursuing the relationship between p-creativity in development, and h-creativity in experts may actually further both accounts. Adopting a developmental perspective on creativity, as was done in chapter 9, where creativity of all types is necessary: mapping, exploring and transforming conceptual spaces, highlights the need to clarify how they relate to one another. Boden's (1992) 'mapping' analogy has not been fully elaborated and relating it to an implementation (e.g. the BAIRN extension proposed above) would require the specific types of 'creativity' to be more tightly defined. The status of the 'maps' would also have to be clarified. It is not entirely clear whether the map need to be a separate entity from the conceptual space, or whether it just describes the flexibility inherent in the subjective conceptual space.

Accounts of h-creativity could benefit from analysis of 'transformations' of conceptual spaces in childhood. The

developmental discontinuities caused by the creation of a new knowledge level in children may provide useful information to explain h-creative creative leaps. Boden (1992) and indeed A.I. has more to say about the mapping and exploring of conceptual spaces, than the transformation of them.

At various points in this thesis surprise has been suggested as a potential stimulus to Re-Representation, and it is associated in creativity. Surprise has been found in the animal literature to improve learning (Lieberman, Davidson, and Thomas, 1985). The interaction between surprise and representational change, whilst merely suggestive at this stage, seems to be worth pursuing.

#### **4. Recursive Re-Representation and Activity Theory.**

A comparison between Activity theory and the Recursive Re-Representation account may be usefully explored, the former being dealt with superficially in this thesis. The predictions of the two accounts appear to have many similarities, although the explanations differ.

"consciousness and control appear only at a late stage in the development of a function, after it has been used and practiced unconsciously and spontaneously. In order to subject a function to intellectual control, we must first possess it."

Vygotsky 1962 (p. 90)

The 3R's account predicts an increase in awareness with development, because the child has the knowledge which enables her to think things that she could not think before, rather than because of the internalisation of social regulation processes. However, the 3R's

modifications had been mapped out for the children, and the task transformed into one of making a specified local contextual change which they were able to perform. However, the youngest children did not create their own variants of the example modifications, whereas the older children did, the latter requiring an overview to make their own comparisons.

In a further experiment subjects would again be asked to draw a 'strange man', to test their spontaneous modification type. The prediction being that younger children will produce only local changes and the older children will produce both global and local changes. The spontaneous production phase could be followed up with requests for each of the specified modifications, (excepting the one the child spontaneously produced), however without providing the specific examples which were given in the original study. In this case the youngest children should have more difficulty producing the modifications which require an overview.

## **5.2 Block balancing**

Karmiloff-Smith's block balancing experiment produces an interesting rigidity in performance, when children are only able to balance evenly-weighted blocks. However, a longitudinal study would have to be carried out to ascertain whether this was a *necessary* developmental stage. It has been suggested that the level 1/phase 2 rigidity may emerge from the knowledge not being integrated with other knowledge, but emanating from school experience of balancing. Presenting subjects with the unevenly weighted blocks in a building task, for example, might allow them to operate differently on the blocks, if the specific piece of balancing knowledge was not directly called.

A more elaborate and controlled version of the experiment reported in chapter 4 would allow further comparison of the subjects performance and of their analysis of the blocks. A more detailed evaluation of the effect of various block features (e.g. overall weight) on performance could also be undertaken. It was found that children in the chapter 4 study thought overall weight was a factor before they could distinguish this from un-even weight.

The blocks could be constructed in a systematic fashion, varying two perceptual features: overall weight and conspicuous asymmetries. There would be two evenly-weighted blocks, although one of these should be heavy and the other one light. Blocks with hidden weights could be manufactured with centres of balance 10%, 20%, 30% and 40% off centre. Two conspicuously-weighted blocks could balance at 20% and 40% off centre, thus having direct centre-of-balance counterparts with the hidden-weighted block. This would allow an evaluation of the effects of the visual features of the block as distinct from the intrinsic balancing properties of the blocks. An additional category which would prove useful in analysing subject perceptions would be two apparently-weighted blocks, which contained hidden weights and actually balanced in the centre. One of these should be relatively heavy and the other light.

To assess the subject's perceptions of the blocks, they could be asked to categorise the blocks into ones which would be 'easy to balance' and those which they thought would be 'difficult to balance'. This could be done both before and after the balancing task, to assess any change due to the task performance.

The main balancing task could be done with a computer representation of the block. This technique has been used successfully



by Joiner et al (in prep.) who compared evenly-weighted with conspicuously-weighted blocks. This computerised presentation could be criticised in that it eliminates the very proprioceptive feedback which is critical to balancing, however it would eliminate problems of manual dexterity, and allow accurate quantification of various other aspects of the task (e.g. time to achieve a balance). Subjects could be presented with each of the blocks on the computer screen, with a pair of hands holding each end. They could move the block in small steps with cursor keys, and then press another key to 'lift the hands' and try a balance. In this experiment they would have the physical blocks available to refer to, which would allow them to analyse the blocks if they so desired. A computerised presentation would provide a record of specific points at which subjects expected a balance, because they would have to remove the 'hands' and would provide a systematic measure of the child's movements of the blocks. Blocks could be colour coded to allow easy comparisons between the computer and real blocks, and the relevant physical block could be handed to children prior to their balancing attempt. The extent to which they analysed the features of the blocks could be extracted from video-tapes. As noted in the chapter 4 study, there may be micro-genetic development with the experimental session. This will be apparent in the categorisation behaviour post-test, and also from the movement and balancing record, and any spontaneous comments.

### **5.3 Planning**

Isaev's planning task provided an interesting progression in planning performance. It was argued that children's development was comparable to the decrement in adult performance with increased cognitive load. A more systematic study of the performance decrements

could be established by allowing adult subjects to stabilise their performance at a given level, by providing more examples. The effect of cognitive load could be controlled by systematically increasing the task difficulty by providing additional carriages and/or additional tracks, extending the task beyond the 5-carriage version.

A further experiment with children could be conducted to systematically assess the role of knowledge of the train set on planning performance. Matched subjects pairs could be used, with only one half being given a chance to familiarise themselves with the operation of the train set prior to engaging with the task. Protocol data could be encouraged by modifying the task so that the children had to explain what they were doing to a teddy bear, or by getting them to instruct the experimenter who would actually move the train.

## **6. Afterword**

This thesis has been built upon the research and insights of Karmiloff-Smith. I have concentrated on the Representational Redescription model, because there are no comparable alternative accounts; it shone to me like a beacon in the fog. Much of the discussion has focussed on negative assessments of the RR model - science progresses through falsification - but it is relatively easy to be critical. It is important to acknowledge Karmiloff-Smith's enormous contribution to developmental psychology and to cognitive science, the RR model being only one small part of that.

I hope that I have progressed Karmiloff-Smith's ideas; I have, at least, risen to her challenge (personal communication, appendix 1) to follow my criticisms by providing an alternative account. However,

Karmiloff-Smith has a large amount of data against which my Recursive Re-Representation account still needs to be tested

I have great respect for Karmiloff-Smith's work, which has been an inspiration to me. I have learned a great deal from her and look forward to learning more in the future.

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# Appendix 1

## Letter from Karmiloff-Smith.

MRC

Medical Research Council

Your reference

Our reference

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11 December 1990

Dear Fiona

Here are my comments on "Representational Redescription and Children's Drawings" that you sent me some time ago. I am sorry I haven't got back to you earlier.

On page 1 you suggest that the evidence for cognitive development beyond successful performance is the existence of U-shaped behavioural curves. This is not accurate and it is certainly not a necessary component. My narrative work does not really show the U-shaped curve in the sense of external behaviour. What I have been stressing is that a distinction be drawn between behavioural change and representational change. Thus, performance decrement is not the main criteria for phase two. The phases are not defined by behaviour. It's just lucky for the observer that occasionally the behaviour does indeed show behavioural change, but not always in the form of decrement.

Just for your information, the point of balance on Type C blocks is further to the extreme of the block.

Page 3, indeed at the bottom of paragraph 2 you state that behavioural evidence of redescription may not be present for the majority of tasks where redescribed procedures continue to produce correct performance in phase 2. Therefore phase 2 cannot be defined by decrement in performance. Where you refer to "rigidity of the initial redescription", I would replace by a "certain rigidity". My argument is that on the basis on the first redescription children can indeed start to introduce changes. The point is that the first redescription is more restricted than subsequent redescriptions. Page 5, second para., I would stress that the 8 five-year-olds that I tested were carefully selected to be exactly within the category that could only introduce certain types of change and not others.

In general I find your discussion under point 3. that drawings are not Compiled Procedures very apt. I was indeed using the term "compiled" loosely, although I did of course understand what it meant. I was trying to avoid terms such as "autonomized" so that I

*Dictated 2 weeks ago  
but in the Pipeline  
with overworked  
secretaries all  
this time.  
Sorry!  
Haven't re-read  
to save time,  
so forgive  
my English etc!  
Hope useful*

didn't get linked up with the work of John Anderson whose theory is very different. But you are right. The concept "compiled" is very technical and not exactly what I had in mind.

To turn to page 6 now, you really have missed the point here. I am not arguing that the modifications introduced by the 4 to 6 year-old children's drawings are based on a compiled procedure. On the contrary. My point is that the initial procedures become (loosely compiled), but that it is on a redescription of the procedure that the child operates. I think that the 4 to 6 year-olds once they have reached behavioural mastery in drawing can indeed operate on a redescription of a procedure, not of course the procedure itself. Obviously one cannot operate on a procedure, otherwise the notion loses its sense completely. So I am arguing that they build up a procedure, this becomes "autonomised", (loosely compiled or some such notion), then the components of the procedure are redescribed and it is on that redescription that any operation takes place. Obviously I agree that this could not be the case with a compiled procedure, but I have never argued that. Subsequently the elements are accessible at some level and can be modified, but this is via a redescription of the elements embedded in the earlier procedural representation. Indeed, deletion of an element, even if it is only the last element in the sequence, presupposes the existence of identifiable elements but that is exactly my point. It must be on a redescription and not on the procedure itself that this takes place. What I am arguing is that there are multiple levels of redescription, all of which are retained, and that the first one is relatively rigid compared to subsequent redescriptions.

To go on with 4., your question is whether drawings are ever "procedures". I think the basic point that you are making here is well-founded and that the extension to drawings was perhaps an error on my part. However, I would keep stressing, I am not arguing that children modify their procedures. I am arguing that they modify a redescription of their procedures, and that this redescription is sequentially constrained.

I think that you, and another student at Oxford, who have replicated this work, have shown that the sequential constraint on the first level of redescription is considerably weaker than I thought. I can now see why this is. You have not actually provided an explanation. Because I think that it's a good idea to let you push it further, I will wait until you come up with the reason why. It is now extremely clear to me why drawing would be the one area that would not have the same constraints as other areas that I have looked at.

I am still rather surprised by two aspects of your results. One is that the drawings of men that did not exist could, without children's verbal explanations, have been mistaken for normal men. In my case, and we had three judges look at the results, only 9 percent of children failed to draw in any way things that we thought didn't qualify as an X that didn't exist and in those cases it was quite clear from their comments that they simply were unable to do so. Remember that the vast majority of my subjects were successful. That was the whole point in identifying that particular age group. I would not have counted (your page 10) the man that does not exist on the right as a successful drawing because it still looks exactly like a man. But this never occurred in any of my seven-year-olds.

I am also surprised that no drawings fell into changed shaped of the whole category because I had lots and so did the Oxford student.

There is a total misunderstanding on page 10 as to what counts as a modification "mid-

procedure" and I think some of your statistics in fact gloss over this. If the child changes the values on a variable (say, size of ears), this is not what I call "interruption of a procedure". Of course, in my study there were modifications mid-procedure on the values of variables, but the important point was that order was not interrupted. If I had counted changes of values on variables as interruptions, then my results would have looked like yours. The point was to show that although young children could of course make some changes, (because I am looking at children who are successful in making changes), the changes were not of the interruption or change of order sort.

I am surprised that you got all your deletions being made mid-procedure, because this was extremely rare in the younger subjects in my study.

Your statement on page 11 "All but one of these made their modifications in the middles of their 'procedure'" is simply misleading as a comparison to my results, because if young children changed the values on a variable, then that happens at any point in the drawing process. What I was contending was that the redescribed procedure was more rigid than one might have expected and that subsequently the rigidity was relaxed.

I am also surprised that you got children who changed the order completely, i.e. drawing of body before heads and so forth. I didn't have this a single time, so there is something about the task instructions in each case which must have induced children in one case to do so and in the other case not to.

I would never have counted the addition of buttons as "core", but we are probably addressing this in rather a different way. In any case, it seems to me that one does have something sequential like head, face, (then additions to face like beard), body, limbs. Or, head, face, body, (stripes on body), limbs. One might say a head/face drawing procedure followed by a body/limbs drawing procedure in both cases.

One of the problems for me is that your account does not explain all the other sequential constraints that have been found by a number of other authors in various cognitive domains including drawing. You are right about my not accounting for what constitutes "behavioural mastery". I have been trying to do so for a long time and it is not easy! No-one has come up with an operational definition. Again on page 16, I am not talking about evidence for a procedural representation, I am arguing that initial redescription is more sequentially constrained than later redescription. I probably overstated the case in the earlier article, but I still think it holds and it may just be that your beards get put in at the end of a head drawing subroutine but never between one arm drawing and the other arm drawing, for instance. But there's a definite difference between drawing and other domains and your work has highlighted that for me although you haven't actually come up with the explanation yet. I am not being "cute" in not giving it to you. I just think that as a student, (and may I say a very promising rather brilliant one), you ought to find it yourself.

Again on page 17 your conclusion that all children made some of the modifications mid-procedure (? changing values on variables) simply does not address the point that I was making. I agree with you, page 18, that there is a problem of planning (Freeman@s point too). You give a very nice example in the middle of that page.

I am absolutely astounded, page 20, that you had children who began a drawing of a man with the legs. Check with Norman Freeman whether he ever found this. It didn't happen



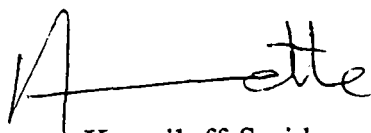
once in my huge population, neither during the piloting phase nor during the actual running of the experiment. I think to be fair on page 21, middle paragraph, you should add the "very specific and testable claims which we have shown cannot be supported *in the drawing domain*." It isn't clear that you show this outside that domain. I agree with you that drawings are not produced by executing compiled procedures. They may, however, still have a procedural-like component which the strict computer metaphor doesn't capture. I think it's difficult to rule out the notion completely because Freeman and many others have talked of formula-like drawing processes which was something like the notion I was trying to capture with my use of procedure. I just think you're right that the actual computational notion is misused in this sense and I agree with you there are probably a continuous series of minor modifications to successive productions rather than a stage of stable success.

In general I really liked your paper, I think there are a lot of excellent points in it but I do not see what your alternative theoretical account is. A general problem with developmental theorising in Britain is the following - I get sent excellent papers with very nice experimental designs which show that a previous researcher has been misguided, and then I turn over to look for the alternative theoretical account and I find the reference list. In your case, you refer very briefly to Vygotsky's theory but make very little of it and I think your paper would be immensely improved if you were to use, say, the Vygotskian account, to give an alternative account of the data and to link it, which I think you must do, to all the work that has shown sequential constraints on phonemic awareness, seriation and so forth, that I refer to.

In any case I think your work has enormous potential and I hope you will continue sending me your up-to-date work. I would point out that a student at Oxford, Ceri Evans, working under Usha Goswami, also did a replication of my drawing work under the title "Flexibility of procedural sequence in children's drawing: A developmental study of representational change". He too found that rigidity of the procedural sequence was not confirmed and also came up with very similar results to the ones that you present although the statistics of his differences between the younger and older age groups were closer to mine. He found results much closer to mine so we have to work out why that is. For example, he got about 20% changes in shape of whole from both age groups and 43% of older age groups made cross category insertions and 9% of the younger age group, which is roughly what I found too. His overall results looked closer to mine than yours do. He, however, recorded the order of productions on videotape and found that my claim that there was such a strong sequential constraint did not hold. I am quite ready to accept that I was wrong on this point, from both your studies. But it is important to recall that I am talking about interruption for sub-routines and not modification mid-procedure for the change of values on variables. You might want to write to Usha and ask her to send you a copy of his work. She is now at the Psychology Department in Cambridge.

Good luck in your future work and do keep me on your mailing list.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Annette', with a stylized flourish extending from the end.

Annette Karmiloff-Smith  
Senior Research Scientist

## Appendix 2

### Karmiloff-Smith & Inhelder (1974) hypothesized developmental sequence.

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#### Action sequence 1:

"Place block at any point of contact, let go; this was immediately followed by a second attempt with the same block: Place at any point of contact, push hard above that point, let go." (p.201)

#### Action sequence 2:

"first place more or less symmetrically on the support bar, i.e. close to the geometric center, correct in the right direction guided by the sensation of falling (adjustments were rarely made in the wrong direction), readjust in the other direction (corrections were frequently excessive), continue correcting back and forth but gradually more carefully until equilibrium is achieved." (p. 202)

#### Action sequence 3:

Place at geometric center, release hold very slightly to observe result, correct very slightly, correct a little more, return carefully to geometric center, repeat until balance is achieved. Depending on the block, the further the child had to move away from the geometric center, the more often he returned to it before further adjusting." (p. 202)

#### Action sequence 4:

First place at geometric center, next place at the point of contact corresponding to the previous success (irrespective as yet of the differences between the two blocks and often far removed from possible empirical success...), return to geometric center, continue as in previous sequence. At this point, some corrections were made away from the center of gravity ..." (p. 202)

#### Action sequence 5:

Place carefully at geometric center, correct very slightly around center, abandon all attempts, declaring the object as 'impossible' to balance.

#### Action sequence 6:

Place at geometric center, correct slightly, pause, lift object, rotate object, pause, place at geometric center, correct position slightly, release hold slightly, readjust carefully, pause longer, glance at conspicuous weight item, pause, place again slowly at geometric center, shake head, glance again at conspicuous weight item, then suddenly correct continuously and rapidly in the right direction until balance is achieved. Repetition of a success was thereafter immediate, even if the object was rotated." (p. 205)

#### Action sequence 7:

To give an indication of of action sequences at the upper level, by 8;7 years of age children paused *before* each item, roughly assessed the weight distribution of the block by lifting it ("you have to be careful, sometimes its just as heavy on each side, sometimes it's heavier on one side"), inferred the probable point of balance and then place the object immediately very close to it, without making any attempts at first balancing at the geometric center." (p. 205)

## Appendix 3

### Isaev Planning Experiment - Instructions to subjects.

-----

You are a train driver and here is your train. Some of the carriages are in the wrong order and you have to get them back into the right order before you can leave. If you look at the example you can see that the carriages need to be in the order 1,2,3, [draw attention to model example] and yours are in the order 3,1,2.

The carriages can only move if they are attached to the engine, but you can attach as many carriages or as few carriages as you like to the engine. So, for example you could just move the first carriage [demonstrate the decoupling procedure], or you could move two carriages [demonstrate], or you could move all three carriages.

You are only allowed to touch the carriages to link them together or to unlink them. You mustn't pick up the carriages, or move them along the track unless the engine is pulling them.

You can move the engine backwards or forwards but you mustn't take the engine off the track.

You can use the engine to split up the train and put some of the carriages onto a different line. For example, I might want to move the first two carriages [3,1] onto this line and leave them there [demonstrate] and then go back and get the other one [2]. If I then attach number 2 to the others I have got the carriages in a new order '2,3,1' instead of the '3,1,2' which we started with. This isn't right yet, because we have to get the order 1,2,3, so you would need to move the train around a bit more. Do you understand how you can move the train? How could I move the first carriage onto this line? [ask to demonstrate] Now can you leave it there and get the second carriage? [ask to demonstrate]. Very good. Do you understand what you have to do? [ask for re-statement of the goal].

There will always be more than one way of rearranging the carriages. For example with this problem [312] you could move the 3, and leave it on this track, then go back and get the 1 & 2 and join them to the 3. Or you could start by taking off the 3 & 1, then go back and get the 2, attach it to the 3 but then split off the 2 & 3 from the 1, move them back then go back for the 1. [These are both demonstrated]. As you can see both ways work, but the first way was quicker. You pretend that your carriages are full of eggs\*, and as you are the train driver you want to move the carriages around as little as possible so that none of the eggs they get broken. You'll need to think very carefully about how you are going to

move the train. Try and tell me what you are thinking about as you sort out this problem.

Are you clear about what you have to do? I'll rearrange the carriages and you can start.